221, 230, 248, and 266i–266j, are respectively provided to D/A converters 270, 274, 278 and 282i–282j where the signals are digitized and provided to summer 286.

Summer 284 sums the PN_I spread data for the pilot, sync, paging and voice channels and while summer 286 sums the and PN_Q spread data for the same channels. The summed I and Q channel data is respectively input along with local oscillator (LO) frequency signals Sin (2πft) and Cos (2πft) to mixers 288 and 290 where they are mixed and provided to summer 292. The LO frequency signals Sin (2πft) and Cos (2πft) are provided from suitable frequency sources (not shown). These mixed IF signals are summed in summer 292 and provided to mixer 294.

Mixer 294 mixes the summed signal with an RF frequency signal provided by frequency synthesizer 296 so as to provide frequency upconversion to the RF frequency band. The RF signal output from mixer 294 is bandpass filtered by bandpass filter 298 and output to RF amplifier 299. Amplifier 299 amplifies the band limited signal in accordance with the input gain control signal from the transmit power control circuitry 56 (FIG. 3). It should be understood that the embodiment illustrated for transmit power amplifier circuitry 58 is merely for purposes of illustration with many variations in signal summing, mixing, filtering and amplification possible as is well known in the art.

Cell-site control processor 48 (FIG. 3) has the responsibility for assignment of digital data receivers and transmit modulators to a particular call. Control processor 48 also monitors the progress of the call, quality of the signals and initiates teardown on loss of signal. The cell-site communicates with the MTSO via link 52 where it is coupled by a standard telephone wire, optical fiber, or microwave link.

FIG. 8 illustrates in block diagram form the equipment utilized in the MTSO. The MTSO typically includes a system controller or control processor 300, digital switch 302, diversity combiner 304, digital vocoder 306 and digital switch 308. Although not illustrated additional diversity combiners and digital vocoders are coupled between digital switches 302 and 308.

When the cell-diversity mode is active, the call is processed by two cell-sites. Accordingly, signals will arrive at the MTSO from more than one cell-site with nominally the same information. However, because of fading and interference on the inbound or reverse link from the mobile unit to the cell-sites, the signal from one cell-site may be of better quality than the signal from the other cell-site.

Digital switch 302 is used in routing the information stream corresponding to a given mobile unit from one or more cell-sites to diversity combiner 304 or the corresponding diversity combiner as determined by a signal from system control processor 300. When the system is not in the cell diversity mode, diversity combiner 304 may be either bypassed or fed the same information on each input port.

A multiplicity of serial coupled diversity combiners and vocoder are provided in parallel, nominally one for each call to be processed. Diversity combiner 304 compares the signal quality indicators accompanying the information bits from the two or more cell-site signals. Diversity combiner 304 selects the bits corresponding to the highest quality cell-site on a frame-by-frame basis of the information for output to vocoder 306.

Vocoder 306 converts the format of the digitized voice signal to standard 64 Kbps PCM telephone format, analog, or any other standard format. The resultant signals is transmitted from vocoder 306 to digital switch 308. Under the control of system control processor 300, the call is routed to the PSTN.

Voice signals coming from the PSTN intended for the mobile units, are provided to digital switch 308 for coupling to an appropriate digital vocoder such as vocoder 306 under control of system control processor 300. Vocoder 306 encodes the input digitized voice signals and provides the resulting information bit stream directly to digital switch 302. Digital switch 302 under system control processor control direct the encoded data to the cell-site or cell-sites to which the mobile unit is communicating. Although discussed previously that information transmitted to the MTSO analog voice, it is further envisioned that digital information may also be communicated in the system. To ensure compatibility with the system, care must be taken in proper framing of the data.

If the mobile unit is in a handoff mode communicating to multiple cell-sites or in a cell diversity mode, digital switch 302 routes the calls to the appropriate cell-sites for transmission by the appropriate cell-site transmitter to the intended recipient mobile unit. However, if the mobile unit is communicating with only a single cell-site or not in a cell diversity mode, the signal is directed only to a single cell-site.

System control processor 300 provides control over digital switches 302 and 306 for routing data to and from the MTSO. System control processor 300 also determines the assignment of calls to the cell-sites and to the vocoders at the MTSO. Furthermore, system control processor 300 communicates with each cell-site control processor about the assignment of particular calls between the MTSO and cell-site, and the assignment of PN codes for the calls. It should be further understood that as illustrated in FIG. 8 digital switches 302 and 306 are illustrated as two separate switches, however, this function may be performed by a single physical switching unit.

When the cell-diversity mode is in use, the mobile unit will use the searcher receiver to identify and acquire the strongest multipath signal from each of the two cell-sites. The digital data receivers will be controlled by the searcher receiver and the control processor so as to demodulate the strongest signals. When the number of receivers is less than the number of cell-sites transmitting information in parallel, a switching diversity capability is possible. For example, with only a single data receiver and with two cell-sites transmitting, the searcher will monitor the pilots from both cell-sites and choose the strongest signal for the receiver to demodulate. In this embodiment the choice can be made as frequently as every vocoder frame, or about every 20 msec.

The system control processor has responsibility for assignment of digital data receivers and modulators at the cell-site to handle particular calls. Thus in the cell-to-mobile link, the system control processor controls the assignment of Walsh sequences used at the cell-site in transmission of a particular call to the mobile unit. In addition the system control processor controls the receiver Walsh sequences and PN codes. In the mobile-to-cell link, the system control processor also controls the mobile unit user PN codes for the call. Assignment information is therefore transmitted from the MTSO to the cell-site and from there to the cell to the mobile. The system control processor also monitors the progress of the call, the quality of signals, and initiates tear down on loss of signal.

MOBILE-TO CELL LINK

In the mobile-to-cell link, the channel characteristics dictate that the modulation technique be modified. In particular, the use of a pilot carrier as is used in the cell-to-mobile link is no longer feasible. The pilot carrier must be more powerful than a voice carrier in order to provide a good phase reference for data modulation. With the cell-site transmitting many simultaneous voice carriers, a single pilot signal can be shared by all the voice carriers. Therefore, the pilot signal power per voice carrier is quite small.

In the mobile-to-cell link, however, there is usually only a single voice carrier per mobile. If a pilot were used, it would require significantly more power than the voice carrier. This situation is clearly not desirable since overall system capacity would be greatly reduced due to the interference caused by the presence of a larger number of high power pilot signals. Therefore, a modulation capable of efficient demodulation without a pilot signal must be used.

With the mobile-to-cell channel corrupted by Rayleigh fading, resulting in a rapidly varying channel phase, coherent demodulator techniques, such as a Costas loop which derives phase from the received signal, are not feasible. Other techniques such as differentially coherent PSK can be employed but fail to provide the desired level of signal-to-noise ratio performance.

Thus, a form of orthogonal signaling such as binary, quaternary or m-ary signalling should be employed. In the exemplary embodiment, a 64-ary orthogonal signaling technique is employed using Walsh functions. The demodulator for m-ary orthogonal signaling requires channel coherence only over the duration of transmission of the m-ary symbol. In the exemplary embodiment, this is only two bit times.

The message encoding and modulation process begins with a convolutional encoder of constraint length $K=9$ and code rate $r=\frac{1}{3}$. At a nominal data rate of 9600 bits per second, the encoder produces 28800 binary symbols per second. These are grouped into characters containing 6 symbols each at a rate of 4800 characters per second with there being 64 possible characters. Each character is encoded into a length 64 Walsh sequence containing 64 binary bits or "chips." The 64-ary Walsh chip rate is 307,200 chips per second in the exemplary embodiment.

The Walsh chips are then "covered" or multiplied by a PN sequence running at the rate of 1.2288 MHz. Each mobile unit is assigned a unique PN sequence for this purpose. This PN sequence can either be assigned only for the duration of the call or assigned permanently to the mobile unit. The assigned PN sequence is referred to herein as the user PN sequence. The user PN sequence generator runs at a clock rate of 1.2288 MHz and so as to produce four PN chips for every Walsh chip.

Finally, a pair of short, length 32768, PN sequences are generated. In the exemplary embodiment, the same sequences are used as for the cell-to-mobile link. The user PN sequence covered Walsh chip sequence is then covered or multiplied by each of the two short PN sequences. The two resulting sequences then bi-phase modulate a quadrature pair of sinusoids and are summed into a single signal. The resulting signal is then bandpass filtered, translated to the final RF frequency, amplified, filtered and radiated by the antenna of the mobile unit.

As was discussed with reference to the cell-to-mobile signal, the ordering of the filtering, amplification, translation and modulation operations may be interchanged.

In an alternative embodiment, two different phases of the user PN code might be produced and used to modulate the two carrier phases of the quadraphase waveform, dispensing with the need for using the length 32768 sequences. In yet another alternative, the mobile-to-cell link might utilize only bi-phase modulation, also dispensing with the need for the short sequences.

The cell-site receiver for each signal produces the short PN sequences and the user PN sequence for each active mobile signal being received. The receiver correlates the received signal energy with each of the coded waveforms in separate correlators. Each of the correlator outputs is then separately processed to demodulate the 64-ary encoding and the convolutional coding using a Fast Hadamard Transform processor and a Viterbi algorithm decoder.

In another alternative modulation scheme for the mobile-to-cell link, the same modulation scheme would be used as for the cell-to-mobile link. Each mobile would utilize the pair of 32768 length sector codes as outer codes. The inner code would utilize a length 64 Walsh sequence that is assigned to the mobile for use while it is in that sector. Nominally, the same Walsh sequence would be assigned to the mobile for the mobile-to-cell link as is used for the cell-to-mobile link.

The above orthogonal PN coding scheme limits the available bandwidth spreading that can be used by the modulation system to a maximum rate of the chip rate divided by 64, or 19200 Hz for the numbers used in the exemplary embodiment. This would preclude the use of m-ary encoding with large m as described for the exemplary embodiment. As an alternative, however, a rate $r=\frac{1}{2}$, constraint length $K=9$ convolutional code could be used with differential binary phase shift keying modulation of the encoded binary symbols. The demodulator in the cell-site could build up a phase reference over a short interval using the technique described in the article "Nonlinear Estimation of PSK-Modulated Carrier with Application to Burst Digital Transmission", Andrew J. Viterbi and Audrey M. Viterbi, IEEE Transactions On Information Theory, Vol IT-29, No. 4, July 1983. For example, a phase reference could be averaged over only 4 symbols requiring no more channel coherence than the above 64-ary scheme.

The performance of the just described alternative scheme, however, will be inferior to the preferred embodiment in the presence of severe Rayleigh fading and multipath conditions. However, in certain environments where fading and multipath are less severe, for example, the satellite-mobile channel and in certain land-mobile channels, the performance of the alternative system could be better than the preferred embodiment. This can occur because the gain from making the mobile signals orthogonal to each other may exceed the loss in detection efficiency of the DPSK scheme.

In order to satisfy the requirement for time alignment in orthogonal Walsh functions for the alternative mobile-to-cell link, each cell receiver determines the time error from nominal timing of each received signal. If a given received signal lags in timing, then the associated cell modulator and transmitter will transmit a small increment. Conversely, if the received signal timing of a mobile leads the nominal timing, a command to retard by a small increment is transmitted to the mobile. The timing adjustment increments are made on the order of

½ PN chip or 101.7 nanoseconds. The commands are transmitted at a relatively low rate, on the order of 10 to 50 Hz and consist of a single bit inserted into the digital voice data flow.

During a soft handoff operation, the mobile unit will be receiving signals from two or more cells. Because the mobile unit can only align its timing in response to one of cells' timing adjust commands, the mobile unit will normally move its timing in response to the commands received from the strongest cell being received. The mobile unit transmitted signal will thus be in time alignment with the cell with which it has the best path. Otherwise greater mutual interference to other users will result.

If each cell receiver receiving a mobile signal performs the above time error measurement and correction transmission operation, then all the mobiles' received signals will normally be received with approximately the same timing, resulting in reduced interference.

FIG. 9 illustrates in block diagram form an exemplary mobile unit CDMA telephone set. The mobile unit CDMA telephone set includes an antenna **430** which is coupled through diplexer **432** to analog receiver **344** and transmit power amplifier **436**. Antenna **430** and diplexer **432** are of standard design and permit simultaneous transmission and reception through a single antenna. Antenna **430** collects transmitted signals and provides them through diplexer **432** to analog receiver **434**. Receiver **434** receives the RF frequency signals from diplexer **432** which are typically in the 850 MHz frequency band for amplification and frequency downconversion to an IF frequency. This translation process is accomplished using a frequency synthesizer of standard design which permits the receiver to be tuned to any of the frequencies within the receive frequency band of the overall cellular telephone frequency band. The signals are also filtered and digitized for providing to digital data receivers **540** and **542** along with searcher receiver **544**.

The details of receiver **434** are further illustrated in FIG. 10. Received signals from antenna **430** are provided to downconverter **500** which is comprised of RF amplifier **502** and mixer **504**. The received signals are provided as an input to RF amplifier **502** where they are amplified and output as an input to mixer **504**. Mixer **504** is provided with another input, that being the signal output from frequency synthesizer **506**. The amplified RF signals are translated in mixer **504** to an IF frequency by mixing with the frequency synthesizer output signal.

The IF signals are output from mixer **504** to bandpass filter (BPF) **508**, typically a Surface Acoustic Wave (SAW) filter having a passband of approximately 1.25 MHz, where they are from bandpass filtered. The characteristics of the SAW filter are chosen to match the waveform of the signal transmitted by the cell-site. The cell-site transmitted signal is a direct sequence spread spectrum signal that is modulated by a PN sequence clocked at a predetermined rate, which in the exemplary embodiment is 1.2288 MHz. This clock rate is chosen to be an integer multiple of the baseband data rate of 9.6 kbps.

The filtered signals are output from BPF **508** as an input to a variable gain IF amplifier **510** where the signals are again amplified. The amplified IF signals are output from IF amplifier **510** to analog to digital (A/D) converter **512** where the signals are digitized. The conversion of the IF signal to a digital signal occurs at a 9.8304 MHz clock rate in the exemplary embodiment which is exactly eight times the PN chip rate. Although (A/D) converter **512** is illustrated as part of receiver **534**, it could instead be a part of the data and searcher receivers. The digitized IF signals are are output from (A/D) converter **512** to data receivers **440** and **442**, and searcher receiver **444**.

Receiver **434** also performs a power control function for adjusting the transmit power of the mobile unit. An automatic gain control (AGC) circuit **514** is also coupled to the output of IF amplifier **510**. In response to the level of the amplified IF signal, AGC circuit **514** provides a feedback signal to the gain control input of IF amplifier **510**. Receiver **434** also uses AGC circuit **514** to generate an analog power control signal that is provided to transmit power control circuitry **438**.

In FIG. 9, the digitized signal output from receiver **434** is provided to digital data receivers **440** and **442** and to searcher receiver **444**. It should be understood that an inexpensive, low performance mobile unit might have only a single data receiver while higher performance units may have two or more to allow diversity reception.

The digitized IF signal may contain the signals of many on-going calls together with the pilot carriers transmitted by the current cell-site and all neighboring cell-sites. The function of the receivers **440** and **442** are to correlate the IF samples with the proper PN sequence. This correlation process provides a property that is well-known in the art as "processing gain" which enhances the signal-to-interference ratio of a signal matching the proper PN sequence while not enhancing other signals. Correlation output is then synchronously detected using the pilot carrier from the closest cell-site as a carrier phase reference. The result of this detection process is a sequence of encoded data symbols.

A property of the PN sequence as used in the present invention is that discrimination is provided against multipath signals. When the signal arrives at the mobile receiver after passing through more than one path, there will be a difference in the reception time of the signal. This reception time difference corresponds to the difference in distance divided by the velocity of propagation. If this time difference exceeds one microsecond, then the correlation process will discriminate between the paths. The receiver can choose whether to track and receive the earlier or later path. If two receivers are provided, such as receivers **440** and **442**, then two independent paths can be tracked and processed in parallel.

Searcher receiver **444**, under control of control processor **446** is for continuously scanning the time domain around the nominal time of a received pilot signal of the cell-site for other multi-path pilot signals from the same cell-site and for other cell-site transmitted pilot signals. Receiver **444** will measure the strength of any reception of a desired waveform at times other than the nominal time. Receiver **444** compares signal strength in the received signals. Receiver **444** provides a signal strength signal to control processor **446** indicative of the strongest signals.

Processor **446** provides control signals to data receivers **440** and **442** for each to process a different one of the strongest signals. On occasion another cell-site transmitted pilot signal is of greater signal strength than the current cell-site signal strength. Control processor **446** then would generate a control message for transmission to the system controller via the current cell-site requesting a transfer of the cell to the cell-site corresponding to the strongest pilot signal. Receivers **440** and **442** may therefore handle calls through two different cell-sites.

During a soft handoff operation, the mobile unit will be receiving signals from two or more cells. Because the mobile unit can only align its timing in response to one of cells' timing adjust commands, the mobile unit will normally move its timing in response to the commands received from the strongest cell being received. The mobile unit transmitted signal will thus be in time alignment with the cell with which it has the best path. Otherwise greater mutual interference to other users will result.

Further details of an exemplary receiver, such as data receiver **440** is illustrated in further detail in FIG. **10**. Data receiver **440** includes PN generators **516** and **518** which generate the PN_I and PN_Q sequences in a manner and corresponding to those generated by the cell-site. Timing and sequence control signals are provided to PN generators **516** and **518** from control processor **446**. Data receiver **440** also includes Walsh generator **520** which provides the appropriate Walsh function for communication with this mobile unit by the cell-site. Walsh generator **520** generates, in response to timing signals (not shown) and a function select signal from the control processor, a signal corresponding to an assigned Walsh sequence. The function select signal transmitted to the mobile unit by the cell-site as part of the call set up message. The PN_I and PN_Q sequences output from PN generators **516** and **518** are respectively input to exclusive-OR gates **522** and **524**. Walsh generator **520** provides its output to both of exclusive-OR gates **522** and **524** where the signals are exclusive-OR'ed and output the sequences PN_I' and PN_Q'.

The sequences PN_I' and PN_Q' are provided to receiver **440** where they are input to PN QPSK correlator **526**. PN correlator **526** may be constructed in a manner similar to the PN correlator of the cell-site digital receivers. PN correlator **526** correlates the received I and Q channel data with the PN_I' and PN_Q' sequences and provides correlated I and Q channel data output to corresponding accumulators **528** and **530**. Accumulators **528** and **530** accumulate the input information over a period of one symbol or 64 chips. The accumulator outputs are provided to phase rotator **532** which also receives a pilot phase signal from control processor **446**. The phase of the received symbol data is rotated in accordance with the phase of the pilot signal as determined by the searcher receiver and the control processor. The output from phase rotator **532** is the I channel data which is provided to the deinterleaver and decoder circuitry.

Control processor **446** also includes PN generator **534** which generates the user PN sequence in response to an input mobile unit address or user ID. The PN sequence output from PN generator **534** is provided to diversity combiner and decoder circuitry. Since the cell-to-mobile signal is scrambled with the mobile user address PN sequence, the output from PN generator **534** is used in descrambling the cell-site transmitted signal intended for this mobile user similar to that as in the cell-site receiver. PN generator **534** specifically provides the output PN sequence to the deinterleaver and decoder circuitry where it is used to descramble the scrambled user data. Although scrambling is discussed with reference to a PN sequence, it is envisioned that other scrambling techniques including those well known in the art may be utilized.

The outputs of receivers **440** and **442** are thus provided to diversity combiner and decoder circuitry **448**. The diversity combiner circuitry contained within circuitry **448** simply adjusts the timing of the two streams of received symbols into alignment and adds them together. This addition process may be proceeded by multiplying the two streams by a number corresponding to the relative signal strengths of the two streams. This operation can be considered a maximal ratio diversity combiner. The resulting combined signal stream is then decoded using a forward error detection (FEC) decoder also contained within circuitry **448**. The usual digital baseband equipment is a digital vocoder system. The CDMA system is designed to accommodate a variety of different vocoder designs.

Baseband circuitry **450** typically includes a digital vocoder (not shown) which may be a variable rate type as disclosed in the previously mentioned copending patent application. Baseband circuitry **450** further serves as an interface with a handset or any other type of peripheral device. Baseband circuitry **450** accommodates a variety of different vocoder designs. Baseband circuitry **450** provides output information signals to the user in accordance with the information provided thereto from circuitry **448**.

In the mobile-to-cell link, user analog voice signals are typically provided through a handset as an input to baseband circuitry **450**. Baseband circuitry **450** includes an analog to digital (A/D) converter (not shown) which converts the analog signal to digital form. The digital signal is provided to the digital vocoder where it is encoded. The vocoder output is provided to a forward error correction (FEC) encoding circuit (not shown) for error correction. In the exemplary embodiment the error correction encoding implemented is of a convolutional encoding scheme. The digitized encoded signal is output from baseband circuitry **450** to transmit modulator **452**.

Transmit modulator **452** first Walsh encodes the transmit data and then modulates the encoded signal on a PN carrier signal whose PN sequence is chosen according to the assigned address function for the call. The PN sequence is determined by control processor **446** from call setup information that is transmitted by the cell-site and decoded by receivers **440** and **442** and control processor **446**. In the alternative, control processor **446** may determine the PN sequence through prearrangement with the cell-site. Control processor **446** provides the PN sequence information to transmit modulator **452** and to receivers **440** and **442** for call decoding.

The output of transmit modulator **452** is provided to transmit power control circuitry **438**. Signal transmission power is controlled by the analog power control signal provided from receiver **434**. Control bits transmitted by the cell-sites in the form power adjustment command are processed by data receivers **440** and **442**. The power adjustment command is used by control processor **446** in setting the power level in mobile unit transmission. In response to this command, control processor **446** generates a digital power control signal that is provided to circuitry **438**. Further information on the relationship of receivers **440** and **442**, control processor **446** and transmit power control **438** with respect to power control is further described in the above-mentioned copending patent application.

Transmit power control circuitry **438** outputs the power controlled modulated signal to transmit power amplifier circuitry 436. Circuitry 436 amplifies and converts the IF signal to an RF frequency by mixing with a frequency synthesizer output signal which tunes the signal to the proper output frequency. Circuitry 436 includes an amplifier which amplifies the power to a final output level. The intended transmission signal is output from circuitry 436 to diplexer 432. Diplexer 432 couples the signal to antenna 340 for transmission to the cell-sites.

Control processor 446 also is capable of generating control messages such as cell-diversity mode requests and cell-site communication termination commands. These commands are provided to transmit modulator 452 for transmission. Control processor 446 is responsive to the data received from data receivers 440 and 442, and search receiver 444 for making decisions relative to handoff and diversity combining.

With respect to transmission by the mobile unit, the mobile user analog voice signal is first passed through a digital vocoder. The vocoder output is then, in sequence, convolutional forward error correction (FEC) encoded, 64-ary orthogonal sequence encoded and modulated on a PN carrier signal. The 64-ary orthogonal sequence is generated by a Walsh function encoder. The encoder is controlled by collecting six successive binary symbol outputs from the convolutional FEC encoder. The six binary collectively determine which of the 64 possible Walsh sequences will be transmitted. The Walsh sequence is 64 bits long. Thus, the Walsh "chip" rate must be $9600 * 3 * (1/6) * 64 = 307200$ Hz for a 9600 bps data transmission rate.

In the mobile-to-cell link, a common short PN sequence is used for all voice carriers in the system, while user address encoding is done using the user PN sequence generator. The user PN sequence is uniquely assigned to the mobile for at least the duration of the call. The user PN sequence is exclusive-OR'ed with the common PN sequences, which are length 32768 augmented maximal-length linear shift register sequences. The resulting binary signals then each bi-phase modulate a quadrature carrier, are summed to form a composite signal, are bandpass filtered, and translated to an IF frequency output. In the exemplary embodiment, a portion of the filtering process is actually carried out by a finite impulse response (FIR) digital filter operating on the binary sequence output.

The modulator output is then power controlled by signals from the digital control processor and the analog receiver, converted to the RF frequency of operation by mixing with a frequency synthesizer which tunes the signal to proper output frequency, and then amplified to the final output level. The transmit signal is then passed on to the diplexer and the antenna.

FIG. 11 illustrates a preferred, but yet exemplary, embodiment of mobile unit transmit modulator 452. Data is provided in digital form from the user digital baseband circuitry to encoder 600 where in the exemplary embodiment is convolutionally encoded. The output of encoder 600 is provided to interleaver 602 which in the exemplary embodiment is a block interleaver. The interleaved symbols are output from block interleaver 602 to Walsh encoder 604 of transmit modulator 452. Walsh encoder 604 utilizes the input symbols to generate a code sequence output. The Walsh sequence is provided to one input of exclusive-OR gate 606.

Transmit modulator 452 further includes PN generator 608 which receives the mobile unit address as an input in determining the output PN sequence. PN generator 608 generates the user specific 42-bit sequence as was discussed with reference to FIGS. 3 and 4. A further attribute of PN generator 608 that is common to all user PN generators and not previously discussed is the use of a masking technique in generating the output user PN sequence. For example, a 42-bit mask is provided for that user with each bit of the 42-bit mask exclusive-OR'ed with a bit output from each register of the series of shift register that form the PN generator. The results of the mask and shift register bit exclusive-OR operation are then exclusive-OR'ed together to form the PN generator output that is used as the user PN sequence. The output PN sequence of PN generator 608, the sequence PN_U, is input to exclusive-OR gate 606. The Walsh symbol data and the PN_U sequence are exclusive-OR'ed in exclusive-OR gate 606 and provided as in input to both of exclusive-OR gates 610 and 612.

Transmit modulator 452 further includes PN generators 614 and 616 which respectively generate PN_I and PN_Q sequences. All mobile units use the same PN_I and PN_Q sequences. These PN sequences are in the exemplary embodiment the zero-shift used in the cell-to-mobile communications. The other input of exclusive-OR gates 610 and 612 are respectively provided with the PN_I and PN_Q sequences output from PN generators 614 and 616. The sequences PN_I and PN_Q are exclusive-OR'ed in the respective exclusive-OR gates with the output provided to transmit power control 438 (FIG. 9).

In the exemplary embodiment, the mobile-to-cell link uses rate $r = \frac{1}{3}$ convolutional code with constraint length $K=9$. The generators for the code are $G_1 = 557$ (octal), $G_2 = 663$ (octal), and $G_3 = 711$ (octal). Similar to the cell-to-mobile link, code repetition is used to accommodate the four different data rates that the vocoder produces on a 20 msec frame basis. Unlike the cell-to-mobile link, the repeated code symbols are not transmitted over the air at lower energy levels, rather only one code symbol of a repetition group is transmitted at the nominal power level. In conclusion, the code repetition in the exemplary embodiment is used merely as an expedient to fit the variable data rate scheme in the interleaving and modulation structure as it will be shown in the following paragraphs.

A block interleaver spanning 20 msec, exactly one vocoder frame, is used in the mobile-to-cell link. The number of code symbols in 20 msec, assuming a data rate of 9600 bps and a code rate $r = \frac{1}{3}$, is 576. The N and B parameters, N is equal to the number of rows and B to the number of columns of the interleaver array are 32 and 18, respectively. The code symbols are written into the interleaver memory array by rows and read out by columns.

The modulation format is 64-ary orthogonal signalling. In other words, interleaved code symbols are grouped into groups of six to select one out of 64 orthogonal waveforms. The 64 time orthogonal waveforms are the same Walsh functions used as cover sequences in the cell-to-mobile link.

The data modulation time interval is equal to 208.33 μsec, and is referred to as a Walsh symbol interval. At 9600 bps, 208.33 μsec corresponds to 2 information bits and equivalently to 6 code symbols at a code symbol rate equal to 28,800 sps. The Walsh symbol interval is subdivided into 64 equal length time intervals, referred to as Walsh chips, each lasting $208.33/64 = 3.25$ μsec. The Walsh chip rate is then $1/3.25$ $\mu sec = 307.2$ kHz.

Since the PN spreading rate is symmetric in the two links, i.e. 1.2288 MHz, there are exactly 4 PN chips per Walsh chip.

A total of three PN generators are used in the mobile-to-cell link path. The user specific 42-bit PN generator and the pair of 15-bit I and Q channel PN generators. Following the user specific spreading operation, the signal is QPSK spread as it was done in the cell-to-mobile link. Unlike the cell-to-mobile link, where each sector or cell was identified by unique sequences of length 2^{15}, here all mobile units use the same I and Q PN sequences. These PN sequences are the zero-shift sequences used in the cell-to-mobile link, also referred to as the pilot sequences.

Code repetition and energy scaling are used in the cell-to-mobile link to accommodate the variable rates produced by the vocoder. The mobile-to-cell link uses a different scheme based on a burst transmission.

The vocoder produces four different data rates, i.e. 9600, 4800, 2400, and 1200 bps, on a 20 msec frame basis as in the cell-to-mobile link. The information bits are encoded by the rate $r=\frac{1}{3}$ convolutional encoder and code symbols are repeated 2, 4, and 8 times at the three lower data rates. Thus, the code symbol rate is kept constant at 28,800 sps. Following the encoder, the code symbols are interleaved by the block interleaver which spans exactly one vocoder frame or 20 msec. A total of 576 code symbols are generated every 20 msec by the convolutional encoder, some of which might be repeated symbols.

The code symbols sequence as it is transmitted is shown in FIG. 12. Notice that a vocoder frame, 20 msec, has been subdivided into 16 slots each lasting 1.25 msec. The numerology of the mobile-to-cell link is such that in each slot there are 36 code symbols at the 28,800 sps rate or equivalently 6 Walsh symbols at the 4800 sps rate. At the $\frac{1}{2}$ rate, i.e. 4800 bps, the slots are grouped into 8 groups each comprising 2 slots. At the $\frac{1}{4}$ rate, i.e. 2400 bps, the slots are grouped into 4 groups each comprising 4 slots, and finally at the $\frac{1}{8}$ rate, i.e. 1200 bps, the slots are grouped into 2 groups each comprising 8 slots.

An exemplary symbol burst transmission pattern is further illustrated in FIG. 12. For example, at the $\frac{1}{4}$ rate, i.e. 2400 bps, during the fourth slot of the first group the fourth and eighth row of the interleaver memory array are read out by columns and sequentially transmitted. The slot position for the transmitted data must be randomized in order to reduce the interference.

The mobile-to-cell link timing is illustrated in FIG. 13. FIG. 13 expands upon the timing diagram of FIG. 7 to include the mobile-to-cell channels, i.e. voice and access. The synchronization of the mobile-to-cell link comprises the following steps:

1. Decode successfully a sync message, i.e. CRC check;
2. Load long PN shift register with state received in the sync message; and
3. Compensate for pilot code phase offset if receiving from a sector which uses a shifted pilot.

At this point the mobile has complete synchronization, i.e. PN synchronization and real time synchronization, and can begin to transmit on either the access channel or voice channel.

The mobile unit in order to originate a call must be provided with signaling attributes in order to complete a call to another system user via a cell-site. In the mobile-to-cell link the envisioned access technique is the slotted ALOHA. An exemplary transmission bit rate on the reverse channel is 4800 bps. An access channel packet comprises of a preamble followed by the information.

The preamble length is in the exemplary embodiment an integer multiple of 20 msec frames and is a sector/-cell parameter which the mobile receives in one of the paging channel messages. Since the cell receivers use the preambles to resolve propagation delays this scheme allows the preamble length to vary based on the cell radius. The users PN code for the access channel is either prearranged or transmitted to the mobile units on the paging channel.

The modulation is fixed and constant for the duration of the preamble. The orthogonal waveform used in the preamble is W_0, i.e. the all zero Walsh function. Notice that an all zero pattern at the input of the convolutional encoder generates the desired waveform W_0.

An access channel data packet may consist of one or at most two 20 msec frames. The coding, interleaving, and modulation of the access channel is exactly the same as for a voice channel at the 9600 bps rate. In an exemplary embodiment, the sector/cell requires the mobile units to transmit a 40 msec preamble and the access channel message type requires one data frame. Let N_P the number of preamble frames where k is the number of 20 msec elapsed from a predefined time origin. Then mobiles are allowed to initiate transmission on the access channel only when the equation: $(k, N_P+2)=0$ is true.

With respect to other communications applications it may be desirable to rearrange the various elements of the error correction coding, the orthogonal sequence coding and the PN coding to better fit the application.

For example, in satellite mobile communications where the signals are relayed between large Hub earth stations and the mobile terminals by one or more earth orbiting satellites, it may be desirable to employ coherent modulation and demodulation techniques in both directions of the link because the channel is much more phase coherent than the terrestrial mobile channel. In such an application, the mobile modulator would not utilize m-ary encoding as described above. Instead, bi-phase or four-phase modulation of forward error correction symbols might be employed with conventional coherent demodulation with carrier phase extracted from the received signal using Costas loop techniques. In addition, the orthogonal Walsh function channelization such as herein described for the cell-to-mobile link may be employed. As long as the channel phase remains reasonably coherent, this modulation and demodulation system provides operation with lower Eb/No than m-ary orthogonal signaling resulting in higher system capacity.

In another embodiment, it may be preferable to encode the speech waveform directly into the RF waveform instead of utilizing a vocoder and FEC techniques. While the use of a vocoder and FEC techniques result in very high link performance, the complexity of implementation is high, resulting in additional cost and in high power consumption. These disadvantages may be especially unfavorable in a pocket portable telephone where battery consumption and cost are important. In customary digital telephone transmission practice, the speech waveform is represented in a digital format as 8 bit speech samples at a sample rate of 8 kHz. The CDMA system could encode the 8 bit samples directly into carrier phase angles. This would eliminate the need for a vocoder or a FEC encoder/decoder. It would also require a somewhat higher signal-to-noise ratio for good performance, resulting in lower capacity. In another alternative, the 8 bit speech samples could be directly encoded into carrier amplitudes. In yet another alternative, the speech waveform samples could be encoded into carrier phases and amplitudes.

The previous description of the preferred embodiments is provided to enable any person skilled in the art to make or use the present invention. The various modifications to these embodiments will be readily apparent to those skilled in the art, and the generic principles defined herein may be applied to other embodiments without the use of the inventive faculty. Thus, the present invention is not intended to be limited to the embodiments shown herein but is to be accorded the widest scope consistent with the principles and novel features disclosed herein.

We claim:

1. A system for modulating an information signal in a spread spectrum communication system, comprising:
   - means for generating an orthogonal function signal representative of an orthogonal function selected from a plurality of orthogonal functions:
   - means for generating a pseudorandom noise (PN) signal of a predetermined PN code;
   - means for combining said orthogonal function signal. said PN signal and an information signal, and for providing a resultant first modulation signal.

2. The system of claim 1 wherein said plurality of orthogonal functions are Walsh functions.

3. The system of claim 1 wherein said PN signal is an augmented length maximal-length linear sequence PN code.

4. A spread spectrum modulator for modulating a digital user information signal for transmission to an intended recipient user, comprising:
   - orthogonal function generator means for generating a preselected Walsh function signal;
   - first combiner means for, receiving and combining said user information signal and said Walsh function signal, and providing a resultant intermediate modulation signal;
   - pseudorandom noise (PN) generator means for generating first and second PN signals of a code sequence different from one another; and
   - second combiner means for, receiving and combining said intermediate modulation signal respectively with said first and second PN signals, and providing resultant first and second output modulation signals.

5. The modulator of claim 4 further comprising encoder means for receiving and error correction encoding said user information signal, and providing an error correction encoded user information signal to said first combiner means for combination with said Walsh function signal.

6. The modulator of claim 5 further comprising interleaver means for receiving and interleaving said error correction encoded user information signal, and providing said interleaved error correction encoded user information signal to said first combiner means for combining with said Walsh function signal.

7. The modulator of claim 6 further comprising transmission means for modulating said first and second output modulation signals upon a carrier signal and transmitting said modulated carrier signal.

8. The modulator of claim 7 wherein said transmission means comprises:
   - signal conversion means for receiving and converting said first and second output modulation signals to analog form;
   - carrier modulation means for, receiving and modulating first and second carrier signals respectively with said analog first and second output modulation signals, and combining said modulated first and second carrier signals as a transmission signal;
   - frequency conversion means for receiving and converting said transmission signal to a higher frequency; and
   - antenna means for radiating said frequency converted transmission signal.

9. The modulator of claim 4 further comprising data scrambler means for generating a scrambling signal unique to said intended recipient user, and said first combining means further for receiving and combining said scrambling signal with said user information signal and said Walsh function signal.

10. The modulator of claim 9 wherein said data scrambler means comprises user PN generator means for generating as said scrambling signal a user PN code sequence unique to said intended recipient user.

11. The modulator of claim 4 wherein said digital user information signal is comprised of frames of variable rate vocoded voice data.

12. A code division multiple access (CDMA) transmission system for spread spectrum modulation and transmission of a plurality of input digital user information signals each intended for a respective recipient user, said transmission system comprising:
   - spreading means for generating first and second spectrum spreading signals;
   - pilot channel means for, generating a pilot channel orthogonal function signal representative of a first orthogonal function selected from a set of orthogonal functions, combining said first and second spectrum spreading signals with said pilot channel orthogonal function signal, and providing as an output first and second pilot channel output signals:
   - a plurality of user channel means each for, receiving a respective one of a plurality of user information signals, generating a user channel orthogonal function signal representative of a selected one of said orthogonal functions of said set of orthogonal functions wherein each user channel orthogonal function signal is of a different orthogonal function with respect to each other user channel orthogonal function signal and said pilot channel orthogonal function signal, combining said received user information signal with said generated user channel orthogonal function signal so as to provide a resultant user channel orthogonalized information signal, combining each resultant user channel orthogonalized information signal with said first and second spectrum spreading signals, and providing as an output from each respective user channel means corresponding first and second user channel output signals;
   - transmission means for, receiving and converting said first and second pilot channel output signals to analog form, receiving and converting each user channel means first and second user channel output signals to analog form, combining said analog first pilot channel output signal and each analog first user channel output signal to provide a first combined signal, combining said analog second pilot channel output signal and each analog second user

channel output signal to provide a second combined signal, combining said first combined signal with a first carrier signal so as to provide a first modulated carrier signal, combining said second combined signal with a second carrier signal so as to provide a second modulated carrier signal, combining said first and second modulated carrier signals as a composite modulated carrier signal, and transmitting said composite modulated carrier signal.

13. The transmission system of claim 12 further comprising at least one auxiliary channel means each for, receiving a respective auxiliary channel information signal, generating an auxiliary channel orthogonal function signal representative of a selected one of said orthogonal functions of said set of orthogonal functions wherein each auxiliary channel orthogonal function signal is of a different orthogonal function with respect to each other auxiliary channel orthogonal function signal, each user channel orthogonal function signal and said pilot channel orthogonal function signal, combining said received auxiliary channel information signal with said generated auxiliary channel orthogonal function signal so as to provide a resultant auxiliary channel orthogonalized information signal, combining each auxiliary channel orthogonalized information signal with said first and second spectrum spreading signals, and providing as an output from each respective auxiliary channel means first and second auxiliary channel output signals to said transmission means; and

said for transmission means further for, receiving and converting each auxiliary channel means first and second auxiliary channel output signals to analog form, combining each analog first auxiliary channel output signal with said analog first pilot channel output signal and each analog first user channel output signal in said first combined signal, combining each analog second auxiliary channel output signal with said analog second pilot channel output signal and each second user channel output signal in said second combined signal

14. The modulator of claim 13 wherein each user channel means is further for forward error correction encoding and interleaving data bits of said user information signal.

15. The modulator of claim 14 wherein each user channel means is further for generating and combining an intended recipient user specific scrambling signal with said encoded and interleaved user information signal.

16. The transmission system of claim 14 wherein said spreading means comprises:

first pseudorandom noise (PN) generator means for generating said first spectrum spreading signal of an In-Phase PN chip code;

second PN generator means for generating said second spectrum spreading signal of a Quadrature-Phase PN chip code; and

wherein said In-Phase and said Quadrature-Phase PN chip codes are each of a different polynomial function.

17. The transmission system of claim 16 wherein said pilot channel means comprises:

pilot channel Walsh function generator means for generating said pilot channel orthogonal function signal comprised of a Walsh function chip sequence of zero state chips;

pilot channel first combiner means for receiving and combining said first spectrum spreading signal with said pilot channel orthogonal function signal, and providing said first pilot channel output signal; and

pilot channel second combiner means for receiving and combining said second spectrum spreading signal with said pilot channel orthogonal function signal, and providing said second pilot channel output signal.

18. The transmission system of claim 17 wherein each user channel means comprises:

user channel Walsh function generator means for generating said respective user channel orthogonal function signal comprised of a selected Walsh function chip sequence of zero and one state chips;

user channel first combiner means for receiving and combining said respective user information signal with said generated user channel orthogonal function signal, and providing said user channel orthogonalized information signal;

user channel second combiner means for receiving and combining said first spreading spectrum signal with said user channel orthogonalized information signal, and providing said first user channel output signal; and

user channel third combiner means for receiving and combining said second spectrum spreading signal with said generated user channel orthogonalized information signal, and providing said second user channel output signal.

19. The transmission system of claim 18 wherein each auxiliary channel means comprises:

auxiliary channel Walsh function generator means for generating said respective auxiliary channel orthogonal function signal comprised of a selected Walsh function chip sequence of zero and one state chips;

auxiliary channel first combiner means for receiving and combining said respective auxiliary information signal with said generated auxiliary channel orthogonal function signal, and providing said auxiliary channel orthogonalized information signal;

auxiliary channel second combiner means for receiving and combining said first spectrum spreading signal with said auxiliary channel orthogonalized information signal, and providing said first auxiliary channel output signal; and

auxiliary channel third combiner means for receiving and combining said second spectrum spreading signal with said generated auxiliary channel orthogonalized information signal, and providing said second auxiliary channel output signal.

20. The modulator of claim 12 wherein each user information signal is comprised of a sequence of fixed time frames of data wherein each data frame is comprised of a variable number of bits of variable rate vocoded voice data.

21. The modulator of claim 20 wherein each input user information signal frame of data further comprises a cyclic redundancy check code (CRCC) bits, said CRCC computed based upon each respective frame data bits.

22. The modulator of claim 21 wherein certain input user information signal data frames of is further comprised of power control bit data.

23. In a code division multiple access (CDMA) cellular telephone system, a cell-site transmission system for spread spectrum modulation and transmission of a plu-

rality of input digital user information signals each containing user information intended for a respective recipient user, said transmissin system comprising:

a spectrum spreading signal generator comprising:

(a) an In-Phase channel pseudorandom noise (PN) generator having an output; and

(b) an Quadrature-Phase channel PN generator having an output;

a pilot channel signal generator comprising:

(a) a pilot channel Walsh function generator having an output;

(b) pilot channel first and second exclusive-OR gates each having a pair of inputs and an output, one input of each of said pilot channel first and second exclusive-OR gates coupled to said pilot channel Walsh function generator output, another input of said pilot channel first exclusive-OR gate input coupled to said In-Phase channel PN generator output, and another input of said pilot channel second exclusive-OR gate input coupled to said Quadrature-Phase channel PN generator output;

(c) pilot channel first and second finite impulse response (FIR) filters each having an input and an output, said pilot channel first FIR filter input coupled to said pilot channel first exclusive-OR gate output and said pilot channel second FIR filter input coupled to said pilot channel second exclusive-OR gate output; and

(d) pilot channel first and second gain control elements each having a pair of inputs and an output, one input of each of said pilot channel first and second gain control elements receiving a respective one of a plurality of gain control signals, another input of said pilot channel gain first control element coupled to said pilot channel first FIR filter output, and another input of said pilot channel second gain control element coupled to said pilot channel second FIR filter output;

a plurality of user channel signal generators each comprising:

(a) a user channel Walsh function generator having an input and an output, each user channel Walsh function generator input receiving a function select signal;

(b) a user channel first exclusive-OR gate having a pair of inputs and an output, one input of said user channel first exclusive-OR gate for receiving a respective input digital user information signal and another input of said user channel first exclusive-OR gate coupled to said user channel Walsh function generator output;

(c) user channel second and third exclusive-OR gates each having a pair of inputs and an output, one input of each of said user channel second and third exclusive-OR gates coupled to said user channel first exclusive-OR gate output, another input of said user channel second exclusive-OR gate input coupled to said In-Phase channel PN generator output, and another input of said user channel third exclusive OR gate input coupled to said Quadrature-Phase channel PN generator output;

(d) user channel first and second FIR filters each having an input and an output, said user channel first FIR filter input coupled to said user channel second exclusive-OR gate output and said user channel second FIR filter input coupled to said user channel third exclusive-OR gate output; and

(e) user channel first and second gain control elements each having a pair of inputs and an output, one input of each of said user channel first and second gain control elements receiving a respective one of said plurality of gain control signals, another input of said user channel first gain control element coupled to said user channel first FIR filter output, and another input of said user channel second gain control element coupled to said user channel second FIR filter output; and

a transmit power amplifier comprising:

(a) first and second sets of digital to analog (D/A) converters, each D/A converter having an input and an output, each D/A converter of said first set having an input coupled to an output of a respective one of said pilot channel first gain control element and said user channel first gain control elements, and each D/A converter of said second set having an input coupled to an output of a respective one of said pilot channel second gain control element and said user channel second gain control elements;

(b) first summer and second summers each having a plurality of inputs and an output, each one of said first summer inputs coupled to an output of a respective D/A converter of said first set of D/A converters and said second summer inputs coupled to an output of a respective D/A converter of said second set of D/A converters;

(c) first and second mixers each having a pair of inputs and an output, one input of said first mixer coupled to said first summer output, another input of said first mixer receiving a first local oscillator signal, one input of said second mixer coupled to said second summer output, and another input of said second mixer receiving a second local oscillator signal;

(d) a third summer having a pair of inputs and an output, one input of said third summer coupled to said first mixer output and another input of said third summer coupled to said second mixer output;

(e) a third mixer having a pair of inputs and an output, one input of said third mixer coupled to said third summer output and another input of said third mixer for receiving an RF carrier signal;

(f) a bandpass filter having an input and an output, said bandpass filter input coupled to said third mixer output; and

(g) a variable gain RF amplifier having a pair of inputs and an output, one input of said RF amplifier coupled to said bandpass filter output, another input of said RF amplifier for receiving an RF power gain control signal and said RF amplifier output for coupling to an antenna system.

24. The transmission system of claim 23 wherein said In-Phase channel PN generator generates from a first polynomial function an In-Phase PN signal and said Quadrature-Phase channel PN generator generates a Quadrature-Phase channel PN signal of a second and different polynomial function.

25. The transmission system of claim 24 wherein said pilot channel Walsh function generator generates a pilot channel Walsh function signal representative of a predetermined Walsh function, and each of said user channel

Walsh function generators generate, in response to a respectively received function select signal, a respective user channel Walsh function signal representative of a different Walsh function with respect to one another and said pilot channel Walsh function.

26. The transmission system of claim 25 wherein each user channel further comprises:

a convolutional encoder having an input and an output, said convolutional encoder input receiving said respective input digital user information signal;

a convolutional interleaver having an input and an output, said convolutional interleaver input coupled to said convolutional encoder output;

a user channel PN generator having an output and capable of generating a user channel PN signal of a user specific PN code;

a user channel fourth exclusive-OR gate having a pair of inputs and an output, one input of said user channel fourth exclusive-OR gate coupled to said user channel PN generator output, another input of said user channel fourth exclusive-OR gate coupled to said convolutional interleaver output, and said user channel fourth exclusive-OR gate output coupled to said one input of said user channel first exclusive-OR gate.

27. The transmission system of claim 23 wherein said pilot channel Walsh function generator generates a pilot channel Walsh function signal representative of a predetermined Walsh function, and each of said user channel Walsh function generators generate, in response to a respectively received function select signal, a respective user channel Walsh function signal representative of a different Walsh function with respect to one another and said pilot channel Walsh function.

28. The transmission system of claim 23 wherein each user channel further comprises:

a convolutional encoder having an input and an output, said convolutional encoder input receiving said respective input digital user information signal; and

a convolutional interleaver having an input and an output, said convolutional interleaver input coupled to said convolutional encoder output and said convolutional interleaver output coupled to said one input of said first user channel exclusive-OR gate.

29. The transmission system of claim 28 wherein each user channel further comprises:

a user channel PN generator having an output and capable of generating a user channel PN signal of a user specific PN code;

a user channel fourth exclusive-OR gate disposed between said convolutional interleaver and said user channel first exclusive-OR gate, said user channel fourth exclusive-OR gate having a pair of inputs and an output, one input of said user channel fourth exclusive-OR gate coupled to said user channel PN generator output, another input of said user channel fourth exclusive-OR gate coupled to said convolutional interleaver output, and said user channel fourth exclusive-OR gate output coupled to said one input of said user channel first exclusive-OR gate.

30. The transmission system of claim 23 further comprising a sync channel signal generator, said sync channel signal generator comprising:

(a) a sync channel Walsh function generator having an output;

(b) a sync channel first exclusive-OR gate having a pair of inputs and an output, one input of said sync channel first exclusive-OR gate for receiving an input digital sync channel information signal bearing system information, and another input of said sync channel first exclusive-OR gate coupled to said sync channel Walsh function generator output;

(c) sync channel second and third exclusive-OR gates each having a pair of inputs and an output, one input of each of said sync channel second and third exclusive-OR gates coupled to said sync channel first exclusive-OR gate output, another input of said sync channel second exclusive-OR gate input coupled to said In-Phase channel PN generator output, and another input of said sync channel third exclusive-OR gate input coupled to said Quadrature-Phase channel PN generator output;

(d) sync channel first and second FIR filters each having an input and an output, said sync channel first FIR filter input coupled to said sync channel second exclusive-OR gate output and said sync channel second FIR filter input coupled to said sync channel third exclusive-OR gate output; and

(e) sync channel first and second gain control elements each having a pair of inputs and an output, one input of each of said sync channel first and second gain control elements receiving a respective one of said plurality of gain control signals, another input of said sync channel first gain control element coupled to said sync channel first FIR filter output, another input of said sync channel second gain control element coupled to said sync channel second FIR filter output, and wherein said sync channel first FIR filter output is coupled to an input of a corresponding D/A converter of said first set and said second sync channel FIR filter output coupled to a corresponding D/A converter of said second set.

31. The transmission system of claim 30 further comprising a paging channel signal generator, said paging channel signal generator comprising:

(a) a paging channel Walsh function generator having an output;

(b) a paging channel first exclusive-OR gate having a pair of inputs and an output, one input of said paging channel first exclusive-OR gate for receiving an input digital paging channel information signal bearing intended recipient user communication request information, and another input of said paging channel first exclusive-OR gate coupled to said paging channel Walsh function generator output;

(c) channel second and third paging exclusive-OR gates each having a pair of inputs and an output, one input of each of said paging channel second and third exclusive-OR gates coupled to said paging channel first exclusive-OR gate output, another input of said paging channel second exclusive-OR gates input coupled to said In-Phase channel PN generator output, and another input of said paging channel third exclusive-OR gate input coupled to said Quadrature-Phase channel PN generator output;

(d) paging channel first and second FIR filters each having an input and an output, said paging channel first FIR filter input coupled to said paging channel second exclusive-OR gate output and said paging channel second FIR filter input coupled to said paging channel third exclusive-OR gate output; and

(e) paging channel first and second gain control elements each having a pair of inputs and an output, one input of each of said paging channel first and second gain control elements receiving a respective one of said plurality of gain control signals, another input of said paging channel first gain control element coupled to said paging channel first FIR filter output, another input of said paging channel second gain control element coupled to said paging channel second FIR filter output, and wherein said paging channel first FIR filter output is coupled to an input of a corresponding D/A converter of said first set and said second paging channel FIR filter output coupled to a corresponding D/A converter of said second set.

32. The transmission system of claim 31 wherein said pilot channel Walsh function generator generates a pilot channel Walsh function signal representative of a first predetermined Walsh function, said sync channel Walsh function generator generates a sync channel Walsh function signal representative of a second predetermined Walsh function, said paging channel Walsh function generator generates a paging channel Walsh function signal representative of a third predetermined Walsh function, and each of said user channel Walsh function generators generate, in response to a respectively received function select signal, a respective user channel Walsh function signal representative of a different Walsh function with respect to one another and said first, second and third predetermined Walsh functions.

33. A method for modulating a digital user information signal for transmission to an intended recipient user, comprising the steps of:

generating a Walsh function signal representative of a Walsh function selected from a plurality of Walsh functions;

combining a user information signal and said Walsh function signal, so as to provide a resultant intermediate modulation signal;

generating at least one spectrum spreading PN signal; and

combining said intermediate modulation signal respectively with each of said spectrum spreading PN signals so as to provide corresponding resultant output modulation signals for transmission to an intended recipient user.

34. The method of claim 33 further comprising the step of error correction encoding said user information signal.

35. The method of claim 34 further comprising the step of interleaving said error correction encoded user information signal.

36. The method of claim 33 further comprising the steps of:

generating a carrier signal;

modulating said first and second output modulation signals upon said carrier signal; and

transmitting said modulated carrier signal.

37. The modulator of claim 33 further comprising the step of:

generating a scrambling signal unique to said intended recipient user; and

combining said scrambling signal with said user information signal and said Walsh function signal.

38. The modulator of claim 37 wherein said scrambling signal is of a user PN code sequence unique to said intended recipient user.

39. In a code division multiple access (CDMA) communication system, a method for spread spectrum modulation and transmission of a plurality of input digital user information signals each intended for a respective recipient user, said method comprising the steps of:

generating first and second spectrum spreading signals;

generating a pilot channel orthogonal function signal representative of a first orthogonal function selected from a set of orthogonal functions;

combining said first and second spectrum spreading signals with said pilot channel orthogonal function signal so as to form first and second pilot channel output signals;

receiving in parallel a plurality of user information signals each intended for a different recipient user;

generating for each received user information signal a respective user channel orthogonal function signal representative of a selected one of said orthogonal functions of said set of orthogonal functions wherein each user channel means orthogonal function signal is of a different orthogonal function with respect to each other user channel orthogonal function signal and said pilot channel orthogonal function signal;

combining each user information signal with a respective user channel orthogonal function signal so as to form a respective resultant user channel orthogonalized information signal;

combining each user channel orthogonalized information signal with said first and second spectrum spreading signals so as to form respective pairs of first and second user channel output signals;

converting said first and second pilot channel output signals to analog form;

converting each each pair of first and second user channel output signals to analog form;

combining said analog first pilot channel output signal and each analog first user channel output signal so as to form a first combined signal;

combining said analog second pilot channel output signal and each analog second user channel output signal so as to form a second combined signal;

generating first and second carrier signals;

combining said first combined signal with said first carrier signal so as to form a first modulated carrier signal;

combining said second combined signal with said second carrier signal, so as to form a second modulated carrier signal;

combining said first and second modulated carrier signals so as to form a composite modulated carrier signal; and

transmitting said composite modulated carrier signal.

40. The method of claim 39 further comprising the steps of:

receiving in parallel at least one respective auxiliary channel information signal;

generating for each received auxiliary channel information signal an auxiliary channel orthogonal function signal representative of a selected one of said orthogonal functions of said set of orthogonal functions wherein each auxiliary channel orthogonal function signal is of a different orthogonal function with respect to each other auxiliary channel orthogonal function signal, each user channel orthogonal function signal and said pilot channel orthogonal function signal;

combining each auxiliary channel information signal with a respective auxiliary channel orthogonal function signal so as to form a respective resultant auxiliary channel orthogonalized information signal;

combining each auxiliary channel orthogonalized information signal with said first and second spectrum spreading signals so as to form respective pairs of auxiliary channel first and second auxiliary channel output signals; and

converting each pair of first and second auxiliary channel output signals to analog form;

combining each analog first auxiliary channel output signal with said analog first pilot channel output signal and each analog first user channel output signal in said first combined signal;

combining each analog second auxiliary channel output signal with said analog second pilot channel output signal and each second user channel output signal in said second combined signal.

41. The method of claim 40 further comprising the steps of forward error correction encoding and interleaving data bits of said user information signal.

42. The method of claim 41 further comprising the steps of generating and combining an intended recipient user specific scrambling signal with said encoded and interleaved user information signal.

43. The method of claim 41 further comprising the step of providing each user information signal as a sequence of fixed time frames of data wherein each data frame is comprised of a variable number of bits of variable rate vocoded voice data.

44. The method of claim 43 further comprising the steps of:

generating, for each frame of each input user information signal, bits of a cyclic redundancy check code CRCC; and

providing said generated CRCC bits in each corresponding frame of each input user information signal.

45. The method of claim 44 further comprising the step of inserting, in certain input user information signal data frames, power control bit data.

46. The method of claim 41 wherein said first spectrum spreading signal is of an In-Phase pseudorandom noise (PN) chip code, said second spectrum spreading signal is of a Quadrature-Phase PN chip code, and said In-Phase and Quadrature-Phase PN chip codes are each generated from a different polynomial function.

47. The method of claim 46 wherein said said pilot channel orthogonal function signal is comprised of a Walsh function chip sequence of zero state chips.

48. The method of claim 47 wherein each user channel orthogonal function signal comprised of a selected Walsh function chip sequence of zero and one state chips.

49. The method of claim 48 wherein each auxiliary channel orthogonal function signal comprised of a selected Walsh function chip sequence of zero and one state chips.

* * * * *

EXHIBIT D.

US005109390A

United States Patent [19]

Gilhousen et al.

[11] **Patent Number: 5,109,390**

[45] **Date of Patent: Apr. 28, 1992**

[54] **DIVERSITY RECEIVER IN A CDMA CELLULAR TELEPHONE SYSTEM**

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[73] Assignee: **Qualcomm Incorporated**, San Diego, Calif.

[21] Appl. No.: **432,552**

[22] Filed: **Nov. 7, 1989**

[51] **Int. Cl.**[5] **H04L 27/30**

[52] **U.S. Cl.** **375/1**; 375/40; 375/100; 455/10; 455/59; 455/68; 455/70; 455/33.2; 455/52.3; 455/56.1; 370/18

[58] **Field of Search** 370/18, 50; 455/33, 455/54, 56, 59, 10, 52, 68, 70; 375/40, 100

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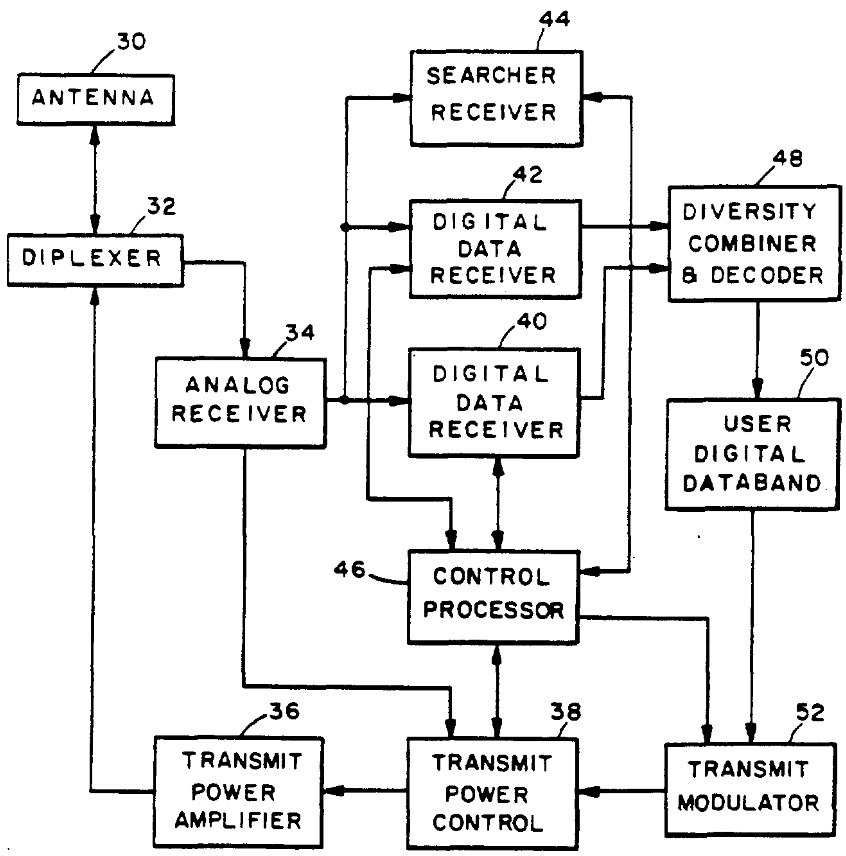
Primary Examiner—Bernarr E. Gregory
Attorney, Agent, or Firm—Russell B. Miller

[57] **ABSTRACT**

A spread spectrum receiver subsystem for utilization in a CDMA cellular telephone having a searcher receiver for scanning the time domain so as to use the PN processing gain and time discrimination properties of spread spectrum coding to determine the location in the time domain and the received signal strength of multiple receptions of a pilot signal traveling upon one or more physical propagation paths to reception. The searcher receiver provides a control signal indicative of the received pilot signals of greatest strength and corresponding time relationship. A data receiver receives spread spectrum communication signals accompanying each received pilot signal and is responsive to the searcher control signal for acquiring and demodulating a spread spectrum communication signal, concomitant with the pilot signal of greatest signal strength, and thus providing a corresponding information bearing encoded output signal.

18 Claims, 4 Drawing Sheets



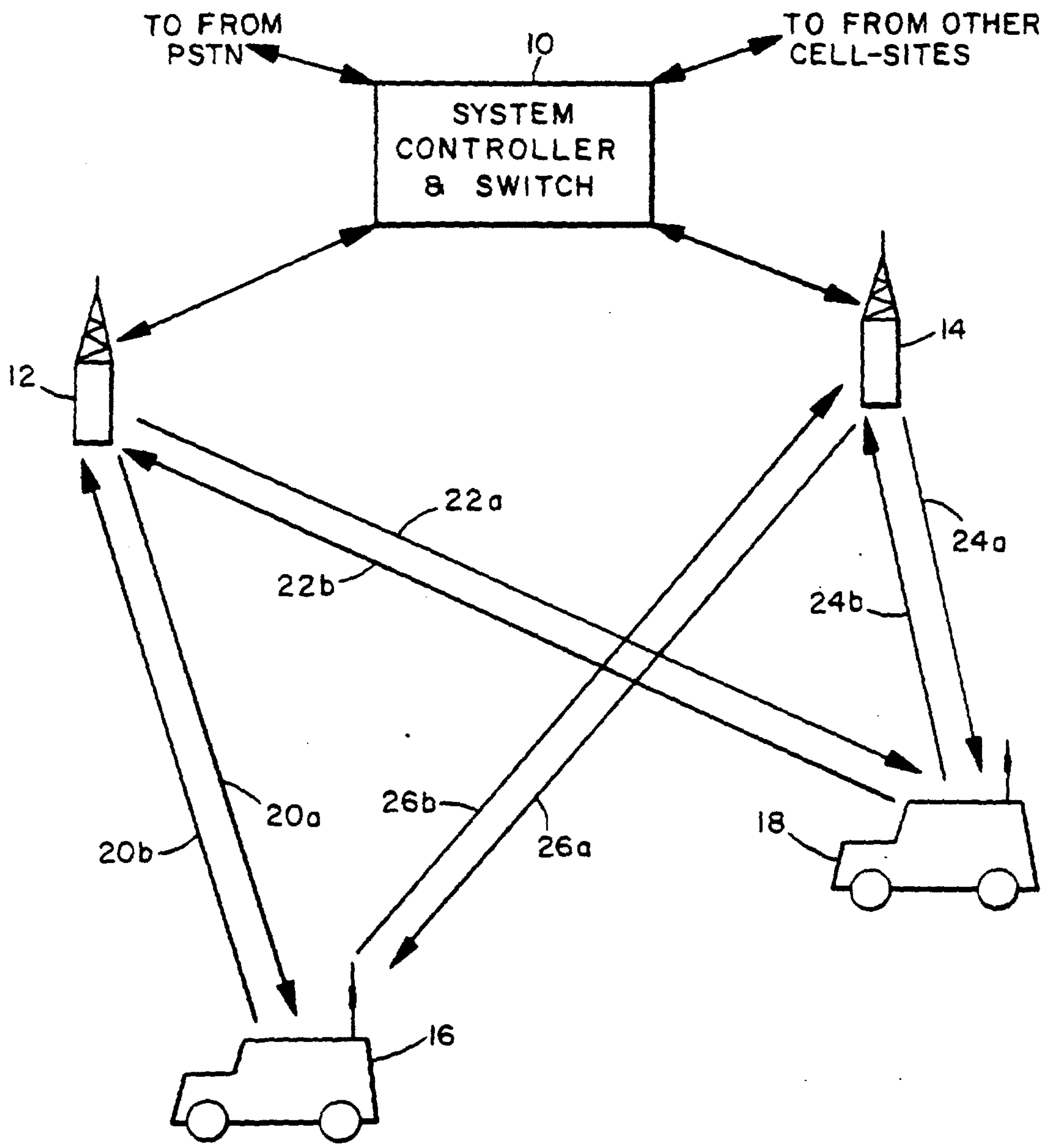

TO FROM
PSTN
10
TO FROM OTHER
CELL-SITES
SYSTEM
CONTROLLER
& SWITCH
12
14
22a
22b
24a
24b
20a
20b
26b
26a
18
16

FIG. 1

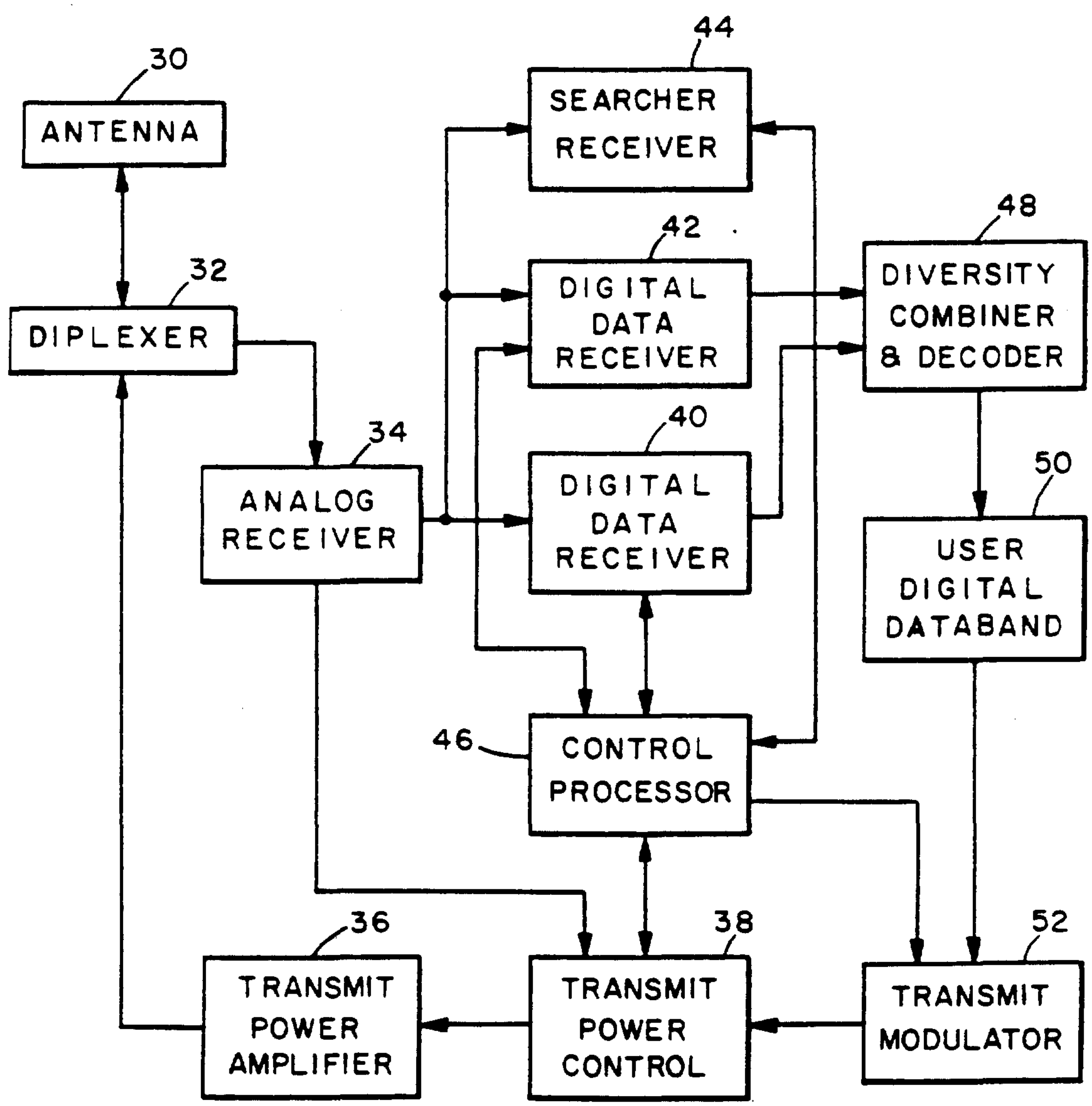

30
ANTENNA
32
DIPLEXER
34
ANALOG RECEIVER
44
SEARCHER RECEIVER
42
DIGITAL DATA RECEIVER
40
DIGITAL DATA RECEIVER
48
DIVERSITY COMBINER & DECODER
50
USER DIGITAL DATABAND
46
CONTROL PROCESSOR
36
TRANSMIT POWER AMPLIFIER
38
TRANSMIT POWER CONTROL
52
TRANSMIT MODULATOR

FIG. 2

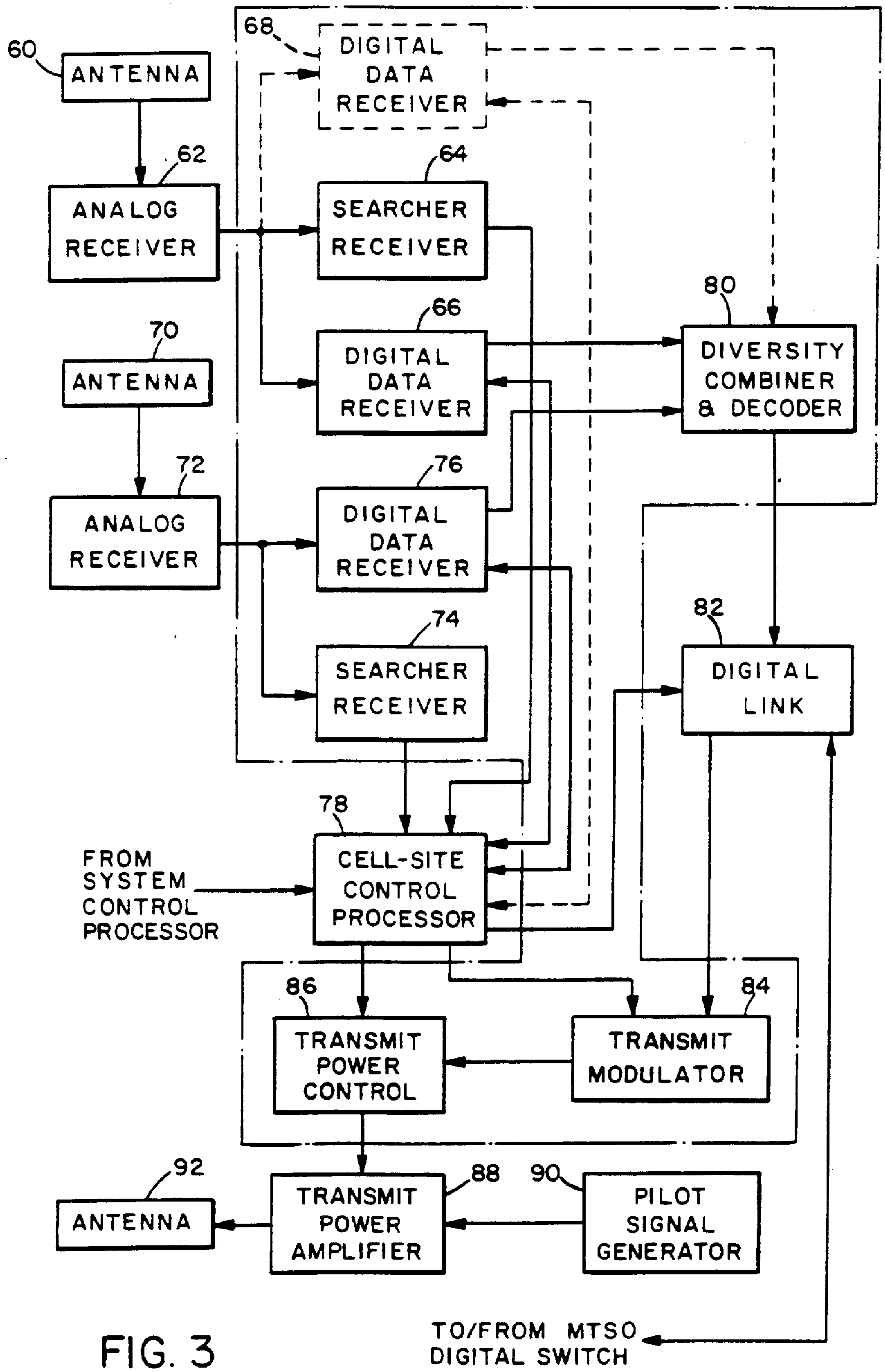

60
ANTENNA
62
ANALOG RECEIVER
68
DIGITAL DATA RECEIVER
64
SEARCHER RECEIVER
66
DIGITAL DATA RECEIVER
70
ANTENNA
72
ANALOG RECEIVER
76
DIGITAL DATA RECEIVER
74
SEARCHER RECEIVER
80
DIVERSITY COMBINER & DECODER
82
DIGITAL LINK
78
CELL-SITE CONTROL PROCESSOR
FROM SYSTEM CONTROL PROCESSOR
86
TRANSMIT POWER CONTROL
84
TRANSMIT MODULATOR
92
ANTENNA
88
TRANSMIT POWER AMPLIFIER
90
PILOT SIGNAL GENERATOR
TO/FROM MTSO DIGITAL SWITCH

FIG. 3

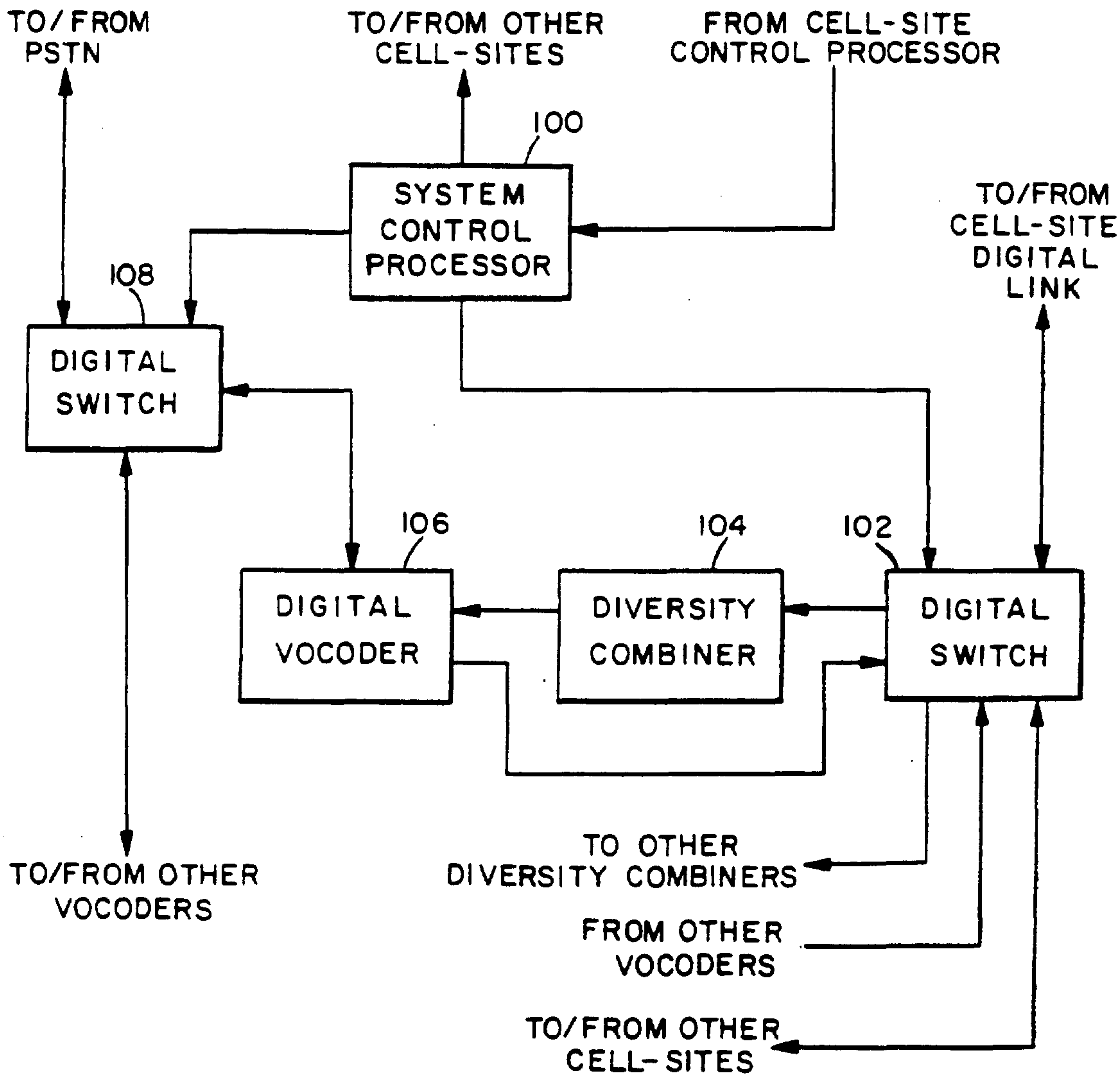

TO/FROM
PSTN
TO/FROM OTHER
CELL-SITES
FROM CELL-SITE
CONTROL PROCESSOR
100
SYSTEM
CONTROL
PROCESSOR
TO/FROM
CELL-SITE
DIGITAL
LINK
108
DIGITAL
SWITCH
106
104
102
DIGITAL
VOCODER
DIVERSITY
COMBINER
DIGITAL
SWITCH
TO/FROM OTHER
VOCODERS
TO OTHER
DIVERSITY COMBINERS
FROM OTHER
VOCODERS
TO/FROM OTHER
CELL-SITES

FIG. 4

DIVERSITY RECEIVER IN A CDMA CELLULAR TELEPHONE SYSTEM

BACKGROUND OF THE INVENTION

I. Field of the Invention

The present invention relates to cellular telephone systems. More specifically, the present invention relates to a novel and improved receiver design for enhancing the reliability and communications in the cellular telephone environment.

II. Description of the Related Art

The use of code division multiple access (CDMA) modulation techniques is one of several techniques for facilitating communications in which a large number of system users are present. Although other techniques such as time division multiple access (TDMA), frequency division multiple access (FDMA) and AM modulation schemes such as amplitude companded single sideband (ACSSB) are known, CDMA has significant advantages over these other techniques. The use of CDMA techniques in a multiple access communication system is disclosed in U.S. Patent application Ser. No. 06/921,261, filed Oct. 17, 1986, entitled "SPREAD SPECTRUM MULTIPLE ACCESS COMMUNICATION SYSTEM USING SATELLITE OR TERRESTRIAL REPEATERS", now U.S. Pat. No. 4,901,307 assigned to the assignee of the present invention, the disclosure thereof incorporated by reference.

In the just mentioned patent, a multiple access technique is disclosed where a large number of mobile telephone system users each having a transceiver communicate through satellite repeaters or terrestrial base stations (also known as cell-sites stations, or for short cell-sites) using code division multiple access (CDMA) spread spectrum communication signals. In using CDMA communications, the frequency spectrum can be reused multiple times thus permitting an increase in system user capacity. The use of CDMA results in a much higher spectral efficiency than can be achieved using other multiple access techniques. In a CDMA system, increases in system capacity may be realized by controlling the transmitter power of each mobile user so as to reduce interference to other system users.

In the satellite application of the CDMA communication techniques, the mobile unit transceiver measures the power level of a signal received via a satellite repeater. Using this power measurement, along with knowledge of the satellite transponder downlink transmit power level and the sensitivity of the mobile unit receiver, the mobile unit transceiver can estimate the path loss of the channel between the mobile unit and the satellite. The mobile unit transceiver then determines the appropriate transmitter power to be used for signal transmissions between the mobile unit and the satellite, taking into account the path loss measurement, the transmitted data rate and the satellite receiver sensitivity.

The signals transmitted by the mobile unit to the satellite are relayed by the satellite to a Hub control system earth station. The Hub measures the received signal power from signals transmitted by each active mobile unit transceiver. The Hub then determines the deviation in the received power level from that which is necessary to maintain the desired communications. Preferably the desired power level is a minimum power

level necessary to maintain quality communications so as to result in a reduction in system interference.

The Hub then transmits a power control command signal to each mobile user so as to adjust or "fine tune" the transmit power of the mobile unit. This command signal is used by the mobile unit to change the transmit power level closer to a minimum level required to maintain the desired communications. As channel conditions change, typically due to motion of the mobile unit, both the mobile unit receiver power measurement and the power control feedback from the Hub continually readjust the transmit power level so as to maintain a proper power level. The power control feedback from the Hub is generally quite slow due to round trip delays through the satellite requiring approximately ½ of a second of propagation time.

One important difference between satellite or terrestrial base stations systems are the relative distances separating the mobile units and the satellite or cell-site. Another important different in the satellite versus the terrestrial system is the type of fading that occurs in these channels. Thus, these differences require various refinements in the approach to system power control for the terrestrial system.

In the satellite/mobile unit channel, i.e. the satellite channel, the satellite repeaters are normally located in a geosynchronous earth orbit. As such, the mobile units are all at approximately the same distance from the satellite repeaters and therefore experience nearly the same propagation loss. Furthermore, the satellite channel has a propagation loss characteristic that follows approximately the inverse square law, i.e. the propagation loss is inversely proportional to the square of the distance between the mobile unit and the satellite repeater in use. Accordingly, in the satellite channel the variation in path loss due to distance variation is typically on the order of only 1-2 dB.

In contrast to the satellite channel, the terrestrial/mobile unit channel, i.e. the terrestrial channel, the distance between the mobile units and the cell sites can vary considerably. For example, one mobile unit may be located at a distance of five miles from the cell site while another mobile unit may be located only a few feet away. The variation in distance may exceed a factor of one hundred to one. The terrestrial channel experiences a propagation loss characteristic as did the satellite channel. However, in the terrestrial channel the propagation loss characteristic corresponds to an inverse fourth-power law, i.e. the path loss is proportional to the inverse of the path distance raised to the fourth power. Accordingly, path loss variations may be encountered which are on the order of over 80 dB in a cell having a radius of five miles.

The satellite channel typically experiences fading that is characterized as Rician. Accordingly the received signal consists of a direct component summed with a multiply reflected component having Rayleigh fading statistics. The power ratio between the direct and reflected component is typically on the order of 6-10 dB, depending upon the characteristics of the mobile unit antenna and the environment about the mobile unit.

Contrasting the satellite channel with the terrestrial channel, the terrestrial channel experiences signal fading that typically consists of the Rayleigh faded component without a direct component. Thus, the terrestrial channel presents a more severe fading environment than the satellite channel where Rician fading is the dominant fading characteristic.

The Rayleigh fading characteristics in the terrestrial channel signal is caused by the signal being reflected from many different features of the physical environment. As a result, a signal arrives almost simultaneously at a mobile unit receiver from many directions with different transmission delays. At the UHF frequency bands usually employed for mobile radio communications, including those of cellular mobile telephone systems, significant phase differences in signals traveling on different paths may occur. The possibility for destructive summation of the signals may result, with on occasion deep fades occurring.

Terrestrial channel fading is a very strong function of the physical position of the mobile unit. A small change in position of the mobile unit changes the physical delays of all the signal propagation paths, which further results in a different phase for each path. Thus, the motion of the mobile unit through the environment can result in a quite rapid fading process. For example, in the 850 MHz cellular radio frequency band, this fading can typically be as fast as one fade per second per mile per hour of vehicle speed. Fading on this order can be extremely disruptive to signals in the terrestrial channel resulting in poor communication quality. However, additional transmitter power can be used to overcome the problem of fading.

The terrestrial cellular mobile telephone system typically requires a full-duplex channel to be provided in order to allow both directions of the telephone conversation to be simultaneously active such as provided by the conventional wired telephone system. This full-duplex radio channel is normally provided by using one frequency band for the outbound link, i.e. transmissions from the cell-site transmitter to the mobile unit receivers. A different frequency band is utilized for the inbound link, i.e. transmissions from the mobile unit transmitters to the cell-site receivers. According, this frequency band separation allows a mobile unit transmitter and receiver to be active simultaneously without feedback or interference from the transmitter into the receiver.

In the conventional cellular telephone system the available frequency band is divided into channels typically 30 KHz in bandwidth while analog FM modulation techniques are used. The system service area is divided geographically into cells of varying size. The available frequency channels are divided into sets with each set usually containing an equal number of channels. The frequency sets are assigned to cells in such a way as to minimize the possibility of co-channel interference. For example, consider a system in which there are seven frequency sets and the cells are equal size hexagons. A frequency set used in one cell will not be used in the six nearest or surrounding neighbors of that cell. Furthermore, the frequency set in one cell will not be used in the twelve next nearest neighbors of that cell.

In the conventional cellular telephone system, the handoff scheme implemented is intended to allow a call to continue when a mobile telephone crosses the boundary between two cells. The handoff from one cell to another is initiated when the cell-site receiver handling the call notices that the received signal strength from the mobile telephone falls below a predetermined threshold value. A low signal strength indication implies that the mobile telephone must be near the cell border. When the signal level falls below the predetermined threshold value, the cell-site asks the system controller to determine whether a neighboring cell-site receives the mobile telephone signal with better signal strength than the current cell-site.

The system controller in response to the current cell-site inquiry sends messages to the neighboring cell-sites with a handoff request. The cell-site neighboring the current cell-site employs special scanning receivers which look for the signal from the mobile unit on the specified channel. Should one of the neighboring cell-sites report an adequate signal level to the system controller, then a handoff will be attempted.

Handoff is then initiated when an idle channel from the channel set used in the new cell-site is selected. A control message is sent to the mobile telephone commanding it to switch from the current channel to the new channel. At the same time, the system controller switches the call from the first cell-site to the second cell-site. In the conventional system a break-before-make scheme is utilized such that no diversity reception is possible in overcoming fades.

Furthermore should the mobile telephone fail to hear the command to switch channels, the handoff will fail. Actual operating experience indicates that handoff failures occur frequently which questions the reliability of the system.

In the conventional cellular telephone system, path fading deleteriously affects communications and can cause disruption in call service. It is therefore an object of the present invention to provide, in a cellular telephone system, receiver a design which facilitates reception and processing of the strongest signals transmitted from one or more cell-sites, these signals being multipath signals from a single cell-site or signals transmitted by multiple cell-sites.

SUMMARY OF THE INVENTION

In a CDMA cellular telephone system, the same frequency band is used for communication in all cells. The CDMA waveform properties that provide processing gain are also used to discriminate between signals that occupy the same frequency band. Furthermore the high speed pseudonoise (PN) modulation allows many different production paths to be separated, provided the difference in path propagation delays exceed the pN chip duration, or one/bandwidth. If a PN chip rate of 1 MHz is employed in a CDMA system, the full spread spectrum processing gain, equal to the ratio of the spread bandwidth to system data rate, can be employed against paths that differ by more than one microsecond in path delay from the desired path. A one microsecond path delay differential corresponds to differential path distance of 1,000 feet. The urban environment typically provides differential path delays in excess of one microsecond, and up to 10–20 microseconds are reported in some areas.

In narrow band modulation systems such as the analog FM modulation employed by conventional telephone systems, the existence of multiple paths results in severe multipath fading. With wideband CDMA modulation, however, the different paths may be discriminated against in the demodulation process. This discrimination greatly reduces the severity of multipath fading. Multipath fading is not totally eliminated in using CDMA discrimination techniques because there will occasionally exist paths with delay differentials of less than the minimum path delay for the particular system. Signals having path delays on this order cannot be discriminated against in the demodulator. It is therefor desirable that the system should provide diversity to further reduce the effects of fading.

The deleterious effects of fading can be controlled somewhat by controlling transmitter power in the CDMA system. A system for cell-site and mobile unit power control is disclosed in copending U.S. Patent Application entitled "METHOD AND APPARATUS FOR CONTROLLING TRANSMISSION POWER IN A CDMA CELLULAR MOBILE TELEPHONE SYSTEM", Ser. No. 07/433,031, filed Nov. 7, 1989, by the inventors hereof and assigned to the Assignee of the present invention. Furthermore the effect of multipath fading can be reduced in the handoff mode when the mobile unit is transitioning between cell-site service area with the mobile unit communicating cell-sites during the handoff process. The handoff scheme is disclosed in copending U.S. Patent Application entitled "SOFT HANDOFF IN A CDMA CELLULAR TELEPHONE SYSTEM", Ser. No. 07/433,030, filed Nov. 7, 1989, by the inventors hereof and assigned to the Assignee of the present invention.

The existence of multipaths can provide path diversity to a wideband PN CDMA system. If two or more paths are available with greater than one microsecond differential path delay, two or more PN receivers can be employed to separately receive these signals. Since these signals will typically exhibit independence in multipath fading, i.e., they usually do not fade together, the outputs of the two receivers can be diversity combined. Therefore a loss in performance only occurs when both receivers experience fades at the same time. Hence, one aspect of the present invention is the provision of two or more PN receivers in combination with a diversity combiner.

Another aspect of the present invention is that as a mobile unit moves through the physical environment, the number of multiple paths and their signals strengths constantly vary. The present invention therefore utilizes a special receiver, called a searcher receiver, which constantly scans the time domain of the channel to determine the existence, the location in the time domain, and the relative signal strengths of signals in the multiple path environment. The searcher receiver provides control over the data receivers in tracking the best signals available on differing paths.

In a CDMA cellular telephone system, each cell-site has a plurality of modulator-demodulator units or spread spectrum modems. Each modem consists of a digital spread spectrum transmit modulator, at least one digital spread spectrum data receiver and a searcher receiver. Each modem at the cell-site is assigned to a mobile unit as needed to facilitate communications with the assigned mobile unit. Therefore in many instances many modems are available for use while other ones may be active in communicating with respective mobile units. A soft handoff scheme is employed for a CDMA cellular telephone system in which a new cell-site modem is assigned to a mobile unit while the old cell-site continues to service the call. When the mobile unit is located in the transition region between the two cell-sites, the call can be switched back and forth between cell-sites as signal strength dictates. Since the mobile unit is always communicating through at least one cell-site, no disrupting effects to the mobile unit or in service will occur. The present invention utilizes multiple receivers at the mobile unit which are also used in a diversity function when in the handoff process or firmly in a single cell.

In the CDMA cellular telephone system, each cell-site transmits a "pilot carrier" signal. This pilot signal is used by the mobile units to obtain initial system synchronization and to provide robust time, frequency and phase tracking of the cell-site transmitted signals.

Each cell-site also transmits a "setup" channel comprised of spread spectrum modulated information, such as cell-site identification, system timing, mobile paging information and various other control signals. The pilot signal transmitted by each cell-site is of the same spreading code but with a different code phase offset. Phase offset allows the pilot signals to be distinguished from one another resulting in distinguishment between cell-sites from which they originate. Use of the same pilot signal code allows the mobile unit to find system timing synchronization by a single search through all pilot signal code phases. The strongest pilot signal, as determined by a correlation process for each code phase, is readily identifiable. The identified pilot signal corresponds to the pilot signal transmitted by the nearest cell-site.

Upon acquisition of the strongest pilot signal, i.e. initial synchronization of the mobile unit with the strongest pilot signal, the mobile unit searches for the appropriate setup channel of that cell-site. The setup channel is transmitted by the cell-site using one of a plurality of different predetermined spread spectrum codes. In an exemplary embodiment of the present invention, twenty-one different codes are used. However, it should be understood that more or less codes could be used in the setup channel as determined by system parameters. The mobile unit then begins a search through all of the different codes used in the setup channel.

When the mobile unit identifies the appropriate setup code for that cell-site, system information is received and processed. The mobile unit further monitors the setup channel for control messages. One such control message would indicate a call is waiting for transfer to this mobile unit.

The mobile unit continues to scan the received pilot carrier signal code at the code offsets corresponding to neighboring cell-site transmitted pilot signals. This scanning is done in order to determine if the pilot signal emanating from neighboring cells is becoming stronger than the pilot signal first determined to be strongest. If, while in this call inactive mode, a neighbor cell-site pilot signal becomes stronger than that of the initial cell-site transmitted pilot signal, the mobile unit will acquire the stronger pilot signals and corresponding setup channel of the new cell-site.

When a call is initiated, a pseudonoise (PN) code address is determined for use during the course of this call. The code address may be either assigned by the cell-site or be determined by prearrangement based upon the identity of the mobile unit. After a call is initiated the mobile unit continues to scan the pilot signal transmitted by cell-sites located in neighboring cells. Pilot signal scanning continues in order to determine if one of the neighboring cell-site transmitted pilot signals becomes stronger than the pilot signal transmitted by the cell-site the mobile unit is in communication with. When the pilot signal transmitted by a cell-site located in a neighboring cell becomes stronger than the pilot signal transmitted by a cell-site in the current cell, it is an indication to the mobile unit that a new cell has been entered and that a handoff should be initiated. In response to this pilot signal strength determination, the mobile unit generates and transmits a control message to the cell-site presently servicing the call. This control message, indicative that a new cell-site transmitted pilot signal is now stronger than the current cell-site transmitted pilot signal, is provided to the system controller. The control message further contains information identifying the new cell-site and PN code. The control message as relayed to the system controller is interpreted that a handoff in mobile unit communications to the identified new cell-site is to begin.

The system controller now begins the handoff process. It should be understood that during handoff the PN code address of the particular mobile unit which is to undergo the handoff process need not change. The system controller begins the handoff by assigning a modem located in the new cell-site to the call. This modem is given the PN address associated with the call in communications between the mobile unit and the current cell-site modem. The new cell-site modem assigned to service the call searches for and finds the mobile unit transmitted signal. The cell-site modem also begins transmitting an outbound signal to the mobile unit. The mobile unit searches for this outbound signals in accordance with the signal and setup channel information provided by the new cell-site. When the new cell-site modem transmitted signal is acquired, the mobile unit switches over to listening to this signal. The mobile unit then transmits a control message indicating that handoff is complete. The control message is provided by either or both of the old and new cell-site modems to the system controller. In response to this control message the system controller switches the call over to the new cell-site modem alone while discontinuing the call through the old cell-site modem. The old cell-site modem then enters a pool of idle modems available for reassignment.

However, when the mobile unit is within a single cell service area, in which the cell-site signals are multipath signals, the corresponding cell-site transmitted signals are stronger than any other cell-site transmitted signals which may be received at the mobile unit. In the single cell mode of operation, the searcher receiver monitors the multipath signals and identifies the strongest as received on the various multipaths. The searcher receiver provides this information to the mobile unit control processor which instructs the data receivers to track the signals upon these strongest paths. The signals are then output from the data receivers where they are provided to a diversity combiner.

During call handoff, mobile unit communications with the various cell-sites is subject to path diversity. These communications are also processed by the multiple receivers at the mobile unit for diversity combination. Furthermore the signals transmitted through the various cell-sites are combined in a diversity combiner at the system controller. The present invention further permits what is referred to herein as the cell-site diversity mode at times other than a handoff. In this mode the mobile unit is permitted to communicate with various cell-sites on an ongoing basis.

In the cell-site diversity mode the call is allowed to linger in the in-between state as described above with reference to the call being processed by two cell-sites. In the exemplary embodiment described herein with reference to the mobile telephone of the present invention, a total of three demodulator processors or receivers are utilized. One of the receivers is used for the scanning function, while the two other receivers are used as a two channel diversity receiver. During operation in a single cell, the scanning receiver attempts to find the cell-site transmitted signal travelling upon multiple paths to the mobile unit. These multipath signals are typically caused by reflections of the signals by the terrain buildings and other signals obstructions. When two or more such reflections are found, the two receivers are assigned to the two strongest paths. The scanning receiver continues to evaluate the multiple paths to keep the two receivers synchronized with signals on the two strongest paths as path conditions change.

In the cell-site diversity mode, the strongest paths from each cell-site is determined by the search receiver. The two receivers are assigned to demodulate the signals on the strongest two paths of the paths available from the original cell-site and from the new cell-site. The data demodulation process uses information from both of these receivers in a diversity combining operation. The result of this diversity combining operation is a greatly improved resistance to deleterious fading that may occur in the multipath cellular telephone environment.

The present invention uses diversity combining to significantly advance the quality and reliability of communications in a mobile cellular telephone system. In the present invention a form of maximal ratio combining is utilized. The signal-to-noise ratio is determined for both paths being combined with the contributions from the two paths weighted accordingly. Combining is coherent since pilot signal demodulation allows the phase of each path to be determined.

In the path from the mobile unit to the two cell-sites, path diversity reception is also obtained by having both cell-sites demodulate the mobile unit transmitted signals. Both cell-sites forward their demodulated data signals to the system controller along with an indication of signal quality in the cell-sites receiver. The system controller then combines the two versions of the mobile unit signal and selects the signal with the best quality indication. It should be understood that it is possible to transmit the undecoded or even the undemodulated signals to the system controller in order to allow a better diversity combining process to be utilized.

The system controller responds by connecting the call to a modem in the new cell-site. The system controller then performs diversity combining of the signals received by the two cell-sites while the mobile unit performs diversity combining of the signals received from the two cell-sites. The cell diversity mode continues as long as signals received from both cell-sites are of a level sufficient to permit good quality demodulation.

The mobile unit continues to search for signals transmitted from other cell-sites. If a third cell-site transmitted signal becomes stronger than one of the original two cell-site signals, the control message is then transmitted by the mobile unit via at least one current cell-site to the system controller. The control message indicates the identity of this cell-site and a request for handoff. The system controller then discontinues the call being communicated via the weakest cell-site signal of the three while providing the call through the two strongest cell-sites. Should the mobile units be equipped with additional receivers, such as three receivers, a triple cell-site diversity mode may be implemented.

The cell-site diversity mode is terminated when the mobile unit determines that only one cell-site is providing adequate signals for quality demodulation. The mobile unit then sends a control message indicative of the cell-site to remain in communication upon termination of the cell-site diversity mode. The cell-site diversity mode may also be terminated by the system controller if the system were to become overloaded with an insufficient number of modems available to support all mobile unit requests for this mode of operation. The cell-site diversity mode as discussed is implemented by decisions being made at the mobile unit to operate in the cell-site diversity mode. However, it should be understood that the cell-site diversity mode can be implemented with the decisions for operation in this mode being made at the system controller. It should also be understood that the cell-site receiver can employ the above described multiple receiver architecture to provide diversity reception when signals arrive at the cell-site from a mobile unit after travelling over paths with greater than one PN chip differential delay.

The present invention provides a substantial improvement over conventional cellular telephone systems with respect to resistance to signal fades by coherently combining multipath signals.

BRIEF DESCRIPTION OF THE DRAWINGS

The features and advantages of the present invention will become more apparent from the detailed description set forth below when taken in conjunction with the drawings in which like reference characters correspond throughout and wherein:

FIG. 1 is a schematic overview of an exemplary CDMA cellular telephone system in accordance with the present invention;

FIG. 2 is a block diagram of a mobile unit telephone configured for CDMA communications in a CDMA cellular telephone system;

FIG. 3 is a block diagram of a cell-site equipment in a CDMA cellular telephone system; and

FIG. 4 is a block diagram of a mobile telephone switching office equipment.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

An exemplary telephone system in which the present invention is embodied is illustrated in FIG. 1. The system illustrated in FIG. 1 utilizes CDMA modulation techniques in communication between the system mobile units or mobile telephones, and the cell-sites. Cellular systems in large cities may have hundreds of cell-site stations serving hundreds of thousands of mobile telephones. The use of CDMA techniques readily facilitates increases in user capacity in systems of this size as compared to conventional FM modulation cellular systems.

In FIG. 1, system controller and switch 10, also referred to as mobile telephone switching office (MTSO), typically includes interface and processing circuitry for providing system control to the cell-sites. Controller 10 controls the routing of telephone calls from the public switched telephone network (PSTN) to the appropriate cell-site for transmission to the appropriate mobile unit. Controller 10 also controls the routing of calls from the mobile units, via at least one cell-site to the PSTN. Controller 10 may direct calls between mobile users via the appropriate cell-site stations since such mobile units do not typically communicate directly with one another.

Controller 10 may be coupled to the cell-sites by various means such as dedicated telephone lines, optical fiber links or by microwave communication links. In FIG. 1, two such exemplary cell-sites 12 and 14, along with mobile units 16 and 18 each including a cellular telephone are illustrated. Arrows 20a-20b and 22a-22b respectively define the possible communication links between cell-site 12 and mobile units 16 and 18. Similarly, arrows 24a-24b and arrows 26a-26b respectively define the possible communication links between cell-site 14 and mobile units 16 and 18. Cell-sites 12 and 14 nominally transmit using equal power.

The cell-site service areas or cells are designed in geographic shapes such that the mobile unit will normally be closest to one cell-site. When the mobile unit is idle, i.e. no calls in progress, the mobile unit constantly monitors the pilot signal transmissions from each nearby cell-site. As illustrated in FIG. 1, the pilot signals are respectively transmitted to mobile unit 16 by cell-sites 12 and 14 upon communication links 20a and 26a. The mobile unit then determines which cell it is in by comparing signal strength of pilot signals transmitted from these particular cell-sites.

Mobile unit 16 measures the total received power in pilot signals transmitted by cell-sites 12 and 14 upon path 20a and 26a. Similarly, mobile unit 18 measures the total received power in pilot signals as transmitted by cell-sites 12 and 14 upon paths 22a and 24a. In each of mobile units 16 and 18, pilot signal power is measured in the receiver where the signal is a wideband signal Accordingly, this power measurement is made prior to correlation of the received signal with a pseudonoise (PN) spectrum spreading signal.

When mobile unit 16 is closer to cell-site 12, the received signal power will be dominated by the signal traveling path 20a. When mobile unit 16 is nearer to cell-site 14, the received power will be dominated by the signal traveling on path 26a. Similarly, when mobile unit 18 is closer to cell-site 14, the received power will be dominated by the signal on path 24a. When mobile unit 18 is closer to cell-site 12, the received power will be dominated by the signal traveling on path 22a.

Each of mobile units 16 and 18 use the resultant measurement, together with knowledge of the cell-site transmitter power and the mobile unit antenna gain, in estimating the path loss to the closest cell-site. The estimated path loss, together with knowledge of the mobile antenna gain and the cell-site G/T (receive antenna gain G divided by receiver noise level T) is used to determine the nominal transmitter power required to obtain the desired carrier-to-noise ratio in the cell-site receiver. The knowledge by the mobile units of the cell-site parameters may be either fixed in memory or transmitted in cell-site information broadcast signals, setup channel, to indicate other than nominal conditions for a particular cell-site.

In the example illustrated in FIG. 1, mobile unit 16 may be considered closest to cell-site 12. When mobile unit 16 initiates a call, a control message is transmitted to the nearest cell-site, cell-site 12. Cell-site 12 upon receiving the call request message, signals system controller 10 and transfers the call number. System controller 10 then connects the call through the PSTN to the intended recipient.

Should a call be initiated within the PSTN, controller 10 transmits the call information to all the cell-sites in the area. The cell-sites in return transmit a paging message to the intended recipient mobile unit. When the mobile unit hears a paging message, it responds with a control message that is transmitted to the nearest cell-site. This control message signals the system controller that this particular cell-site is in communication with the mobile unit. Controller 10 then routes the call through this cell-site to the mobile unit.

Should mobile unit 16 move out of the coverage area of the initial cell-site, cell-site 12, an attempt is made to continue the call by routing the call through another cell-site. In the handoff process there are two different methods of initiating the handoff of the call or routing through another cell-site.

The first method, called the cell-site initiated message, is similar to the handoff method employed in the original first generation analog cellular telephone systems currently in use. In the cell-site initiated method, the initial cell-site, cell-site 12, notices that the signal transmitted by mobile unit 16 has fallen below a certain threshold level. Cell-site 12 then transmits a handoff request to system controller 10. Controller 10 relays the request to all neighboring cell-sites, including cell-site 14. The controller transmitted request includes information relating to the channel, including the PN code sequence used by mobile unit 16. Cell-site 14 tunes a receiver to the channel being used by the mobile unit and measure the signal strength, typically using digital techniques. If cell-site 14 receivers report a stronger signal than the initial cell-site reported signal strength, then a handoff is made to this cell-site.

The second method of initiating a handoff is called the mobile initiated handoff. The mobile unit is equipped with a search receiver which is used to scan the pilot signal transmission of neighboring cell-sites, in addition to performing other functions. If a pilot signal of cell-site 14 is found to be stronger than the pilot signal of cell-site 12, mobile unit 16 transmits a control message to the current cell-site, cell-site 12. This control message contains information identifying the cell-site of greater signal strength in addition to information requesting a handoff of this cell-site. Cell-site 16 transfers this control message to controller 10.

The mobile initiated handoff method has various advantages over the cell-site initiated handoff method. The mobile unit becomes aware of changes in paths between itself and the various neighboring cell-sites much sooner and with less effort than the cell-sites are capable of doing. However, to perform a mobile initiated handoff, each mobile unit must be provided with a searching receiver to perform the scan function. In the exemplary embodiment described herein of a mobile unit with CDMA communications capability, the search receiver has additional functions which require its presence.

When mobile unit 16 is within the coverage area of cell-site 14, such that the transmitted signals of cell-site 14 are the strongest, mobile unit 16 searcher receiver utilizes multipath signals of strongest strength for processing in the multiple data receivers.

Should mobile unit 16 move out of the coverage area of the initial cell-site, cell-site 12, an attempt is made to continue the call by routing the call through another cell-site. In the cell diversity mode the call is routed through multiple cell-sites. The use of the diversity receiver system of the present invention enables communications between mobile unit 16 and cell-sites 12, 14 and various other cell-sites.

FIG. 2 illustrates in block diagram form the mobile unit. The mobile unit includes an antenna 30 which is coupled through diplexer 32 to analog receiver 34 and transmit power amplifier 36. Antenna 30 and diplexer 32 are of standard design and permit simultaneous transmission and reception through a single antenna. Antenna 30 collects transmitted signals and provides them through diplexer 32 to analog receiver 34. Receiver 34 receives the RF frequency signals from diplexer 32 which are typically in the 850 MHz frequency band for amplification and frequency downconversion to an IF frequency. This translation process is accomplished using a frequency synthesizer of standard design which permits the receiver to be tuned to any of the frequencies within the receive frequency band of the overall cellular telephone frequency band.

The IF signal is then passed through a surface acoustic wave (SAW) bandpass filter which in the preferred embodiment is approximately 1.25 MHz in bandwidth. The characteristics of the SAW filter are chosen to match the waveform of the signal transmitted by the cell-site which has been direct sequence spread spectrum modulated by a PN sequence clocked at a predetermined rate, which in the preferred embodiment is 1.25 MHz. This clock rate is chosen to be an integer multiple of a number of common data rates such as 16 Kbps, 9.6 Kbps, and 4.8 Kbps.

Receiver 34 also performs a power control function for adjusting the transmit power of the mobile unit. Receiver 34 generates an analog power control signal that is provided to transmit power control circuitry 38.

Receiver 34 is also provided with an analog to digital (A/D) converter (not shown) for converting the IF signal to a digital signal with conversion occurring at a 9.216 MHz clock rate in the preferred embodiment which is exactly eight times the PN chip rate. The digitized signal is provided to each of two or more signal processors or data receivers, one of which is a searcher receiver with the remainder being data receivers.

In FIG. 2, the digitized signal output from receiver 34 is provided to digital data receivers 40 and 42 and to searcher receiver 44. It should be understood that an inexpensive, low performance mobile unit might have only a single data receiver while higher performance units may have two or more to allow diversity reception.

The digitized IF signal may contain the signals of many on-going calls together with the pilot carriers transmitted by the current and all neighboring cell-sites. The function of the receivers 40 and 42 are to correlate the IF samples with the proper PN sequence. This correlation process provides a property that is well-known in the art as "processing gain" which enhances the signal-to-interference ratio of a signal matching the proper PN sequence while not enhancing other signals. Correlation output is then synchronously detected using the pilot carrier from the closest cell-site as a carrier phase reference. The result of this detection process is a sequence of encoded data symbols.

A property of the PN sequence as used in the present invention is that discrimination is provided against multi-path signals When the signal arrives at the mobile receiver after passing through more than one path, there will be a difference in the reception time of the signals. This reception time difference corresponds to the difference in distance divided by the speed of light. If this time difference exceeds one microsecond, then the correlation process will discriminate against one of the paths. The receiver can choose whether to track and receive the earlier or later path. If two receivers are provided, such as receivers 40 and 42, then two independent paths can be tracked and in parallel.

Searcher receiver 44, under control of control processor 46 is for continuously scanning the time domain around the nominal time of a received pilot signal of the cell-site for other multipath pilot signals from the same cell-site and for other cell-site transmitted pilot signals. Receiver **44** will measure the strength of any reception of a desired waveform at times other than the nominal time. Receiver **44** compares signal strength in the received signals. Receiver **44** provides a signal strength signal to control processor **46** indicative of the strongest signals and relative time relationship.

Processor **46** provides signals to control digital data receivers **40** and **42** for each to process a different one of the strongest signals. On occasion another cell-site transmitted pilot signal is of greater signal strength than the current cell-site signal strength. Control processor **46** then would generate a control message for transmission to the system controller via the current cell-site requesting a transfer of the call to the cell-site corresponding to the stronger pilot signal. Receivers **40** and **42** may therefor handle calls through two different cell-sites.

The outputs of receivers **40** and **42** are provided to diversity combiner and decoder circuitry **48**. The diversity combiner circuitry contained within circuitry **48** simply adjusts the timing of the two streams of received signals into alignment and adds them together. This addition process may be proceeded by multiplying the two streams by a number corresponding to the relative signal strengths of the two streams. This operation can be considered a maximal ratio diversity combiner. The resulting combined signal stream is then decoded using a forward stream error detection decoder also contained within circuitry **48**.

In the exemplary embodiment convolutional encoding is utilized. The convolutional encoding has a constraint length 9 and a code rate $\frac{1}{3}$, i.e. three encoded symbols are produced and transmitted for every information bit to be transmitted. The optimum decoder for this type of code is of the soft decision Viterbi algorithm decoder design. The resulting decoded information bits are passed to the user digital baseband circuitry **50**.

Baseband circuitry **50** typically includes a digital vocoder (not shown). Baseband circuitry **50** further serves as an interface with a handset or any other type of peripheral device. Baseband circuitry **50** accommodates a variety of different vocoder designs. Baseband circuitry **50** provides output information signals to the user in accordance with the information provided thereto from circuitry **48**.

User analog voice signals typically provided through a handset are provided as an input to baseband circuitry **50**. Baseband circuitry **50** includes an analog to digital (A/D) converter (not shown) which converts the analog signal to digital form. The digital signal is provided to the digital vocoder where it is encoded. The vocoder output is provided to a forward error correction encoding circuit (not shown) for error correction. This voice encoded digitized voice signal is output from baseband circuitry **50** to transmit modulator **52**.

Transmit modulator **52** modulates the encoded signal on a PN carrier signal whose PN sequence is chosen according to the assigned address function for the call. The PN sequence is determined by control processor **46** from call setup information that is transmitted by the cell-site and decoded by receivers **40** and **42**. In the alternative, control processor **46** may determine the PN sequence through pre-arrangement with the cell-site. Control processor **46** provides the PN sequence information to transmit modulator **52** and to receivers **40** and **42** for call decoding. The output of transmit modulator **52** is provided to transmit power control circuitry **38**. Signal transmission power is controlled by the analog power control signal provided from receiver **34**. Control bits are transmitted by the cell-sites in the form power adjustment command and are processed by data receivers **40** and **42**. The power adjustment command is used by control processor **46** in setting the power level in mobile unit transmission. In response to this command, control processor **46** generates a digital power control signal that is provided to circuitry **38**. Further information on the interrelationship of the receivers **40** and **42**, control processor **46** and transmit power control circuitry **38** are also further described in the above-mentioned copending patent application.

Transmit power control circuitry **38** outputs the power controlled modulated signal to transmit power amplifier circuitry **36**. Circuitry **36** amplifies and converts the IF signal to an RF frequency by mixing with a frequency synthesizer output signal which tunes the signal to the proper output frequency. Circuitry **36** includes an amplifier which amplifies the power to a final output level. The intended transmission signal is output from circuitry **36** to diplexer **32**. Diplexer **32** couples the signal to antenna **30** for transmission to the cell-sites.

Control processor **46** also is capable of generating control messages such as cell-diversity mode requests and cell-site communication termination commands. These commands are provided to transmit modulator **52** for transmission. Control processor **46** is responsive to the data received from data receivers **40**, **42** and search receiver **44** for making decisions relative to handoff and diversity combining.

FIG. 3 illustrates in block diagram form an exemplary embodiment of the cell-site equipment. At the cell-site, two receiver systems are utilized with each having a separate antenna and analog receiver for space diversity reception. In each of the receiver systems the signals are processed identically until the signals undergo a diversity combination process. The elements within the dashed lines correspond to elements corresponding to the communications between the cell-site and one mobile unit. The output of the analog receivers are also provided to other elements used in communications with other mobile units.

In FIG. 3, the first receiver system is comprised of antenna **60**, analog receiver **62**, searcher receiver **64** and digital data receiver **66**. This receiver system may also include an optional digital data receiver **68**. The second receiver system includes antenna **70**, analog receiver **72**, searcher receiver **64** and digital data receiver **66**. Also utilized in signal processing and control for handoff and diversity is cell-site control processor **78**. Both receiver systems are coupled to diversity combiner and decoder circuitry **80**. Digital link **82** is utilized to communicate signals to and from the MTSO (FIG. 4) with cell-site transmit modulator **84** and circuitry **80** under the control of control processor **78**.

Signals received on antenna **60** are provided to analog receiver **62**. Received signals amplified by an amplifier in receiver **62** and translated to an IF frequency by mixing with a frequency synthesizer output signal. The IF signals are bandpass filtered and digitized in a process identical to that described with reference to the mobile unit analog receiver. The digitized IF signals are provided to digital data receiver **66**, optional data receiver **68** and searcher receiver **64** and are processed